The Horace Dobell Lectures

ON

INSECT PORTERS OF BACTERIAL INFECTION

Delivered at the Royal College of Physicians of London, November, 1912

BY

CHARLES J. MARTIN, D.Sc., M.B. LOND., F.R.S.

DIRECTOR OF THE LISTER INSTITUTE OF PREVENTIVE MEDICINE
PROFESSOR OF EXPERIMENTAL PATHOLOGY IN THE
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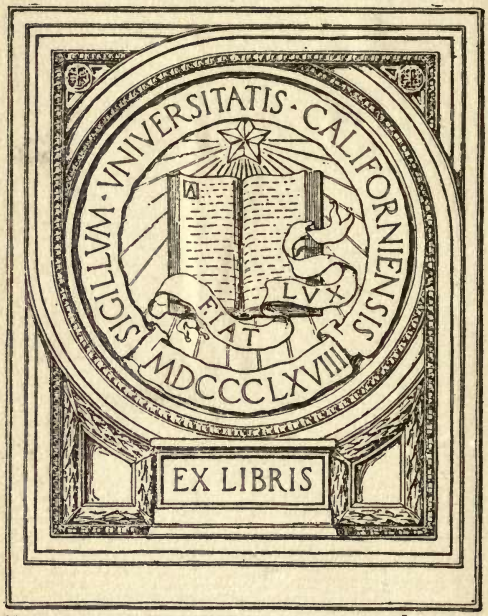
Reprinted from THE LANCET, January 4 and 11, 1913



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LECTURE I.

MR. PRESIDENT,—I would first of all express to you, Sir, and the Censors of the College my appreciation of the honour you have done me in electing me to deliver the Horace Dobell lecture. I feel, however, that it will be impossible for me to do justice to the fine spirit which actuated the founders of the lectureship during their lives' work.

To successfully interfere in bacterial diseases of man and animals it is most important to know accurately the life-history of the parasite outside the host—how it leaves the old host, how it enters a new host, and where and how it passes the intervening period. If we are in possession of these facts our efforts in the struggle can at any rate be intelligently directed and concentrated against the most vulnerable point of the enemy. The exercise of an adverse influence upon bacteria, once they have gained a footing in the body, has hitherto not been generally successful, although recent developments in chemotherapy have shown that there is ground for optimism in this direction also.

In the early days of bacteriology, before the large number of pathogenic bacteria had been discovered and their peculiarities had been studied, it was generally assumed that bacteria once let loose from the body survived long periods upon inanimate objects and in water, soil, &c. ; and efforts at prevention were directed to an indiscriminate disinfection of the belongings and surroundings of the patient. Some bacteria do, indeed, possess considerable powers of survival under such circumstances, and I would not be understood to deprecate measures of general disinfection. The majority of pathogenic organisms, however, are fortunately delicate creatures, and rapidly succumb to such adverse influences as drying and sunlight.

Another factor which must not be lost sight of is that many organisms which have acquired by selection the property of withstanding the adverse influence obtaining in the

animal body fare ill in the competition with hardy saprophytic colleagues outside the body, and if certain individuals do survive, these, whilst acquiring the capacity to live upon extra-corporeal nutriment, diminish at the same time in pathogenicity. In other words, the conditions select a strain tending more and more towards saprophytism and away from parasitism. For these reasons it behoves us to be especially on the look out for any machinery through the agency of which bacteria may be rapidly conveyed from sick to healthy, and their travels made easier for them.

In not a few diseases the infective agent usually passes almost directly from patient to patient—such are syphilis, plague-pneumonia, diphtheria, measles, scarlet fever, small-pox, and numerous parasitic skin diseases. The spread of such highly infectious diseases can be dealt with by isolation and segregation of contacts, for their range is small.

Of recent years much attention has been bestowed upon the study of the rôle of insects in the transmission of disease. It is not my intention to deal with these discoveries as to the essential part played by insects in the transmission of protozoal parasites made by Smith and Kilbourne, Bruce, Ross; Reed, Carrol, and Agramonte in the case of the transmission of Texas fever, nagana, sleeping sickness, malaria of birds and animals, and yellow fever respectively. It may, however, be pointed out that it was these researches which focused attention upon the possibility of bacterial diseases being conveyed by a similar agency. In the latter case the insect plays a less essential part, and no particular phase in the life-history of the parasite takes place within it. I have accordingly, following a suggestion of my friend Colonel Alcock,[1] employed the term "porters" to describe this passive rôle of insects in the spread of contagion.

House Flies.

A deal of attention has been paid to flies lately, in view of their possible influence in the dissemination of infection, more particularly in the case of such diseases as cholera, typhoid fever, and infantile diarrhœa, where the infective agent escapes from the intestine and new infections are taken in by the mouth.

The first question is, Can the fly convey infection? Before referring to the numerous experiments which have afforded an answer, I will briefly refer to those points in the life-history, structure, and habits of the house fly which are of assistance in appreciating how it may play such a rôle. These subjects have been submitted to careful inquiry during the

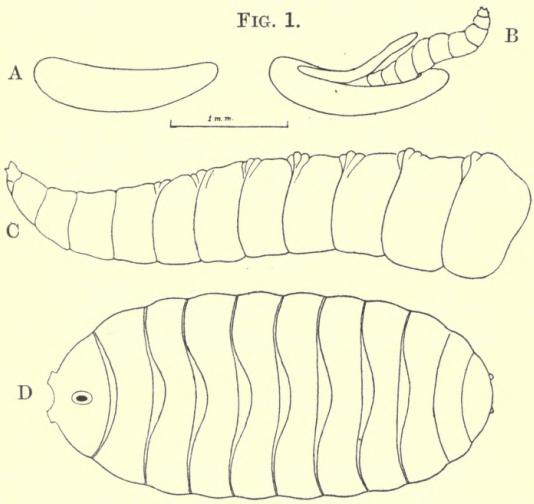
[1] Entomology for Medical Officers, London, 1911.

last few years, particularly in America and this country, and, thanks to the observations of Lowne (1890), Howard (1912), Newstead (1907 and 1909), Griffith (1908), Hewitt (1910), and Graham Smith (1910), we are now well acquainted with this insect, which has perhaps most obtruded itself upon the attention of man, but intimate knowledge of which was, until recently, curiously lacking.

Life-History.

The female fly produces about 120 eggs at each laying, and may produce four broods. Under ordinary conditions the

FIG. 1.



A, The egg. B, The larva emerging. C, The half-grown larva. D, The pupa.

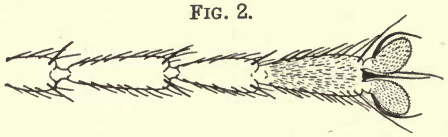
eggs are mostly laid on horse, pig, or cow manure, but the excreta of almost any animal, or other fermenting refuse, suffices. (Fig. 1.) The eggs are sausage-shaped with one end sharp, glistening white in colour, and about 1·5 mm. in length and 0·3 mm. in their greatest diameter. The eggs hatch in from three days to eight hours, according as the temperature ranges from 50° to 80° F. The larva is a little active grub 2 mm. long, with a sharp anterior and a blunt posterior end. The larval stage lasts from five days to three

weeks according to temperature. At the time of pupation it is 6 to 9 mm. in length. Pupation lasts from five days to a month according to temperature. Thus the whole cycle, from laying of egg to emergence of the fly, occupies from ten days to two months, according as the weather be warm or cool. Shortly after emergence from the chrysalis the young fly spreads its wings, which soon harden, and flies away in search of food. The young female is ready to lay its first batch of eggs in about ten days, or even sooner in warm weather.[2] During winter a few flies survive in warm and secluded places. In the spring these start the next year's supply. The possible progeny of one female fly from April to September have been estimated at 10^{15}. Howard, of the United States Department of Agriculture, estimates that in 40 days the descendants of the fly might number 12 millions, or 800 lb. weight.

Structure and Habits.

The only points in the structure of the fly it is essential to direct your attention to are the legs and feet and the general arrangement of the alimentary apparatus. These will be sufficiently obvious in the diagrams. (Figs. 2 and 3.) Please

FIG. 2.



A leg and foot of a fly.

note that the feet are covered with minute hairs. They are, indeed, more numerous and finer than in the diagram, and extremely fine ones are also placed upon the pads (these are stated to secrete a sticky substance by means of which the fly grips), the basal part of the claws, and the distal stiff hair which projects from the end of the last joint of the tarsus. (Fig. 2.) Each leg is like a minute paint brush, which is applied to the surface of whatever it rests upon. When this is water the hairs do not appear to be wetted.

The essential parts of the alimentary canal are a gullet, stomach, crop, intestine, and rectum. (Fig. 3.) The gullet is prolonged to a minute opening between the

[2] No doubt the cycle may be much shorter or longer under a wider range of temperature than that from which these records have been taken.

flaps of the proboscis, halfway down which it is joined by the salivary duct (S.D.). At the entrance to the stomach it is bifurcated, and one limb of the bifurcation is extended backwards to the bilobed crop. By a valvular apparatus at the entrance to the stomach the insect can direct the liquid driven by the pump (P) in its trunk either into the stomach or crop.

The proboscis (P) is a highly elastic muscular organ with universal movement. At the end are two flaps or labella (only one of which is shown, L), which it can open out like the leaves of a book and apply the medial surfaces to the material it feeds upon. From the middle line or hinge minute chitinous channels pass outwards to the margin. These are seen in the diagram of the front view of a fly's

FIG. 3.

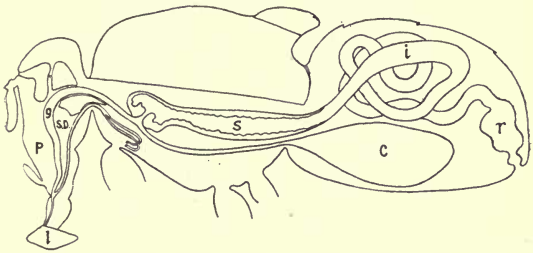


Diagram of alimentary canal and mouth parts of house-fly. P, Pump. *l*, Labella. *g*, Gullet. SD, Salivary duct. S, Stomach. C, Crop. I, Intestine. *r*, Rectum.

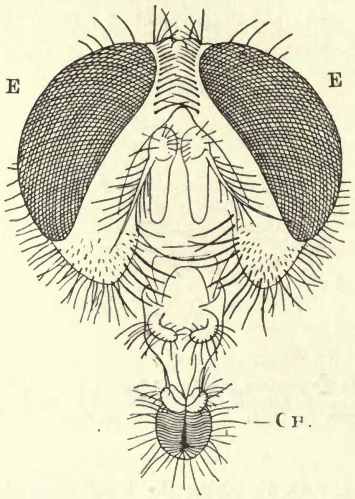
head (Fig. 4, CH), in which the labella are shown opened out and facing forwards. These tubular structures are strengthened at frequent intervals by chitinous rings like a trachea, but are not complete tubes, being open to the surface by a minute linear channel with lateral bays in it. At the base of the trunk a number of muscle fibres are attached to the gullet by the peristaltic contraction of which fluid is pumped up from the mouth and propelled into the stomach or crop.

The structural arrangement of the flaps of the trunk acts as a filter. Graham Smith (1911) is of opinion that solid objects larger than 0·006 mm. seldom pass into the gullet. According to Nicoll (1911), the ova of such tapeworms as do not exceed 0·035 in their smallest diameter may be swallowed. These ova must, therefore, get into the mouth direct. When feeding on a liquid the fly applies the labella to the surface and sucks the liquid through the "strainer"

first of all into the crop. When this is full some goes into the stomach. In the case of solid material, such as sugar, dried blood, or sputum, the insect must first dissolve the material. This is done by pouring saliva upon it, or more generally by regurgitating some of the contents of the crop (Graham Smith, 1910).

Graham Smith (1910) by feeding experiments with coloured syrup found that the meal was first taken into the crop, and subsequently transferred to the stomach at leisure. The fly

FIG. 4.



Front view of a fly's head, showing proboscis and chitinous channels (CH); E, E, Eye.

could, however, fill first its crop and then its stomach. In a quarter of an hour the meal had passed on to the upper third of the intestine, and in a warm incubator at 37° C. reached the rectum within an hour. The fly seems to keep some of the fluid in its crop for days.

A well-fed fly deposits fæces abundantly. Graham Smith (1910) noticed flies defæcating ten times in the first hour after feeding. A curious habit of flies to which, as far as I know, attention was first drawn by Graham Smith, is the regurgitation of the contents of their crops. This has already been referred to as a means by which they are enabled to feed upon dry

material soluble in water. They do this very frequently when walking about over a clean glass, possibly with the idea of extracting nourishment from it. A fly after a good meal may often be seen blowing fluid bubbles from its trunk, and sucking them in again, as in the diagram, Fig. 5, perhaps for practice.

Carriage of Bacterial Infection by Flies.

From the above account it is clear that there are *a priori* reasons for suspecting the fly of carrying bacterial infection. Born in a dunghill, it spends its days flitting between the sugar basin, milk-pan, and any fæcal matter available. Its hairy, probably sticky, feet, and the habit of regurgitating the contents of the crop and defæcating at frequent intervals

FIG. 5.

A fly blowing bubbles.

suggest it to be an excellent inoculating agent for any bacteria it may pick up in the satisfaction of its unsavoury tastes.

That it does, indeed, operate in this way has been abundantly demonstrated. Flies which have wandered over cultures of organisms and afterwards been allowed to walk upon sterile agar plates, leave a rich crop of germs as their footprints, which can be demonstrated by subsequent incubation. Castellani (1907) transferred yaws to monkeys in an analogous way.

The carriage of infection in the alimentary canal and its deposition by regurgitation or fæces has also been shown over and over again (Grassi (1883), Maddox (1885), Alessi (1888), Celli (1888), Sawtchenko (1892), Uffelmann (1892), Yersin (1894), Nuttall (1897), Firth and Horrocks (1902), Manning (1902), Hayward (1904), Lord (1904), Chantemesse (1905), and Buchanan (1907)).

These modes are probably more important than the carriage of bacteria upon the exterior. Many pathogenic

bacteria would soon die from desiccation on the appendages of the insect, and at any rate the number so conveyed is small compared to those contained in its crop and intestine. Carriage within is certainly more lasting, for Graham Smith (1910), to whom we are indebted for the most thorough investigation of this subject, isolated typhoid and other bacilli from the intestinal contents of flies six days after feeding on material containing the organism under test. The fæces ceased to afford growths after two days when typhoid bacilli were the infecting organism used, but with a more robust organism, such as anthrax, which can protect itself from the effects of drying, the time was much longer.

TABLE I.—*Showing the Longest Period after which Organisms were Recovered from Flies Fed on Cultures.*

Organism.	Legs.	Wings.	Head.	Crop.	Gut.	Fæces.
B. typhosus.	—	—	—	—	6 days.	2 days.
B. enteritidis.	7 days.	—	7 days.	8 days.	7 ,,	0 ,,
B. tuberculosis (culture).	—	—	—	3 ,,	16 ,,	13 ,,
B. tuberculosis (sputum).	—	—	—	—	7 ,,	5 ,,
Yeast.	2½ hrs.	2½ hrs.	2½ hrs.	2 days.	3 ,,	2 ,,
B. diphtheriæ.	5 ,,	5 ,,	5 days.	7 ,,	5 ,,	2 ,,
B. anthracis (no spores).	2 days.	—	4 ,,	5 ,,	3 ,,	2 ,,
V. choleræ.	30 hrs.	5 ,,	5 hrs.	2 ,,	2 ,,	30 hrs.
B. prodigiosus.	8 days.	12 ,,	11 days.	5 ,,	17 ,,	6 days.
Anthrax spores.	20 ,,	20 days.	20 ,,	13 ,,	20 ,,	13 ,,

The accompanying table (Table I.), taken from Dr. Graham Smith's report, summarises the result of his experiments on the length of time during which various bacilli can be recovered from the outside and inside of flies fed on infected material. As the author is careful to point out, gross infection was produced in these experiments by feeding upon pure cultures, and they do not do more than indicate the duration of life of various pathogenic bacteria under favourable conditions.

Bacot (1911), Ledingham (1911), and Graham Smith (1911) have further shown that in the case of larvæ fed on material infected with various organisms—*B. pyocyaneus*, *B. typhosus*, and *B. anthracis* respectively—the infection may be carried through the chrysalis stage and recovered from the contents of the intestine of the fly after emergence. Fortunately,

however, according to Ledingham, *B. typhosus* leads a precarious existence in competition with the natural bacterial flora of the larvæ and pupæ.

There are numerous recorded instances in which the pathogenic organisms of cholera, typhoid fever, phthisis, anthrax, and plague have been recovered from the interior or dejections of flies which have been captured in the immediate neighbourhood of cases of the disease, or in the last two, of carcasses of animals dead from the disease. Cholera vibrios were isolated from wild flies under these circumstances by Tizzoni and Cattani (1886), Simmonds (1892), and Tsuzuki (1904); typhoid bacilli by Hamilton (1903), Ficker (1903), Faichnie (on seven occasions) (1909), Cochrane (1912), and Bertarelli (1910); tubercle bacilli by Spillmann and Haushalter (1886), Hofmann (1888), Lord (1904), Hayward (1904), Cobb (1905), and Buchanan (1907); anthrax by Cao; and plague bacilli by Yersin (1894) and Hunter (1906). The spread of ophthalmia in hot countries has, on good grounds, been attributed to the agency of flies in carrying the Koch-Weeks bacillus and the gonococcus from eye to eye (Budd (1862), Laveran (1880), Howe (1888), and Axenfeld (1907)). The seasonal and local prevalence of ophthalmia corresponds with that of flies, and a visit to Egypt during the fly season is sufficient to convince one that this must happen.

Are Flies the Determining Factor in Epidemics?

Although, however, flies may be discovered with the infection of a number of diseases in or upon them, and by their habits may not unlikely serve as agents in transferring infection, it by no means follows that they are the determining factor of epidemicity in the case of cholera, typhoid, dysentery, &c. In the case of fulminating epidemics of typhoid and cholera associated with an infected water-supply this is obviously not so.

Flies in Relation to Typhoid Fever.

The conclusion that fly transmission is the principal means of spread of typhoid fever in military encampments and stations has been arrived at by a number of competent observers, amongst them being Veeder (1898), Reed, Vaughan, and Shakespeare (1901, in their report on the Origin and Spread of Typhoid Fever in the United States Military Camps during the Spanish War of 1898), Tooth and Calverley Smith (1903), Purdy (1909), and Wanhill (quoted by Purdy).

The sanitary arrangements of a military camp are not exactly those of the Ritz Hotel, and the prevalence of flies

in late summer can hardly be appreciated by those who have not had the experience. The conditions are most favourable for fly transmission, and the circumstantial evidence against flies was so strong as to have left no doubt in the mind of the American Commission that these insects play a large share in disseminating infection, for page 28 of their general statement and conclusions reads thus : " Flies undoubtedly served as carriers of infection."

An estimate of the fly population and its relation to admissions of enteric fever was made by Ainsworth (1909) in Poona. The observations showed that enteric fever had a very definite season, commencing at the end of the hot, dry weather with the onset of the rains, and reaching a maximum a few weeks after their cessation. The abundance of flies increased also soon after the beginning of the rains, but earlier than the admissions for enteric fever, and speaking generally, the fly curve antedated that for cases of enteric fever by about one month. Taking into account the incubation period for the disease, this is in agreement with the view of a causal relation between fever and flies in Poona. The number of observations is unfortunately small.

In considering the possible influence of flies in the spread of typhoid fever in a well-sewered city, it must be remembered that the opportunities for flies to pick up the infection are vastly less than under the conditions of a military encampment, or even in rural surroundings. In large cities, no doubt, dejecta and urine from patients may be left available to flies, but the bulk goes promptly into the main drain. The discovery in cities like London and Manchester of the majority of cases of typhoid fever and their removal to hospital before the period when the excreta contain large numbers of bacilli must also greatly reduce the liability to the dissemination of the disease by flies. The typhoid carriers, however, remain.

Dr. J. Niven (1910) has made observations upon the prevalence of flies in Manchester since 1904. From 12 to 34 bell traps were served out to the inhabitants of small dwellings in different quarters of the town, and the catch was collected every few days by his inspector. By these painstaking observations data have been obtained which, although not extensive, are sufficient to afford information as to the general time relationship between fly prevalence and the incidence of enteric fever and infantile diarrhœa respectively. These observations were communicated to the Epidemiological Section of the Royal Society of Medicine by Dr. Niven in his interesting presidential address in 1910. It must be remembered, however, that the number of flies entrapped in 12 or 17 rooms indicates only in a general way the prevalence of these insects in a large city, so that too much significance must not be attached to other than the main features of the record.

On pp. 62 to 69 of Dr. Niven's paper are plotted the

numbers of cases of enteric fever (commencing) and the diarrhœa deaths for each week of the years from 1891 to 1908. Whilst the latter show well-marked rises during some 10–12 weeks of the summer, the seasonal prevalence of the former is not so striking. Speaking generally, the typhoid season in Manchester is considerably later than the diarrhœa season, and the cases of enteric fever reach a maximum in late autumn at a time when most of the flies have already disappeared. The census of flies commenced in 1904, and coincides for the years 1904-1909 fairly well in time with the diarrhœa deaths, if these are antedated 10 days to allow for the average period ensuing between commencement of the disease and death. If we assume that the same close time relation existed throughout, the observations taken as a whole seem to me to lend little support to the view that typhoid fever in Manchester is to any material extent dependent upon transmission by flies.

The time relation of fly prevalence and cases of typhoid fever was also studied in Washington during 1908 by Rosenau, Lumsden, and Kartle (1909) in collaboration with Howard, entomologist to the United States Department of Agriculture. In Washington in 1908 the flies (musca domestica) appeared in considerable numbers in April and reached a maximum in July. During August and September they steadily diminished to about one-third and rose again in October. The relation of the two curves was not such as to suggest that flies are an important factor in the dissemination of typhoid fever in Washington. In a subsequent report on typhoid fever in Washington, Lennoden and Anderson (1911), from an analysis of the incidence of typhoid fever upon the population using privies or yard closets, discovered that the greater prevalence of the disease among these persons during the summer coincided with the fly season.

Fig. 6 shows the time relation of fly prevalence to notifications of enteric fever for London during 1908. The data are taken from Dr. W. H. Hamer's (1909) observations giving the mean number of flies caught each day in 141 situations grouped around nine centres. The observations being upon a larger scale the sampling was presumably more representative of the fly population than the records in Manchester. I have antedated the records of the number of cases of enteric fever by three weeks, 7 days for average lapse of time prior to notification, and 14 days for average incubation period (Klinger, 1909). It will be seen that the number of cases of enteric fever rises steadily during the fly season, but that the rise continues independent of the fact that flies are rapidly diminishing, and reaches a maximum at a time when they have retired for the winter.

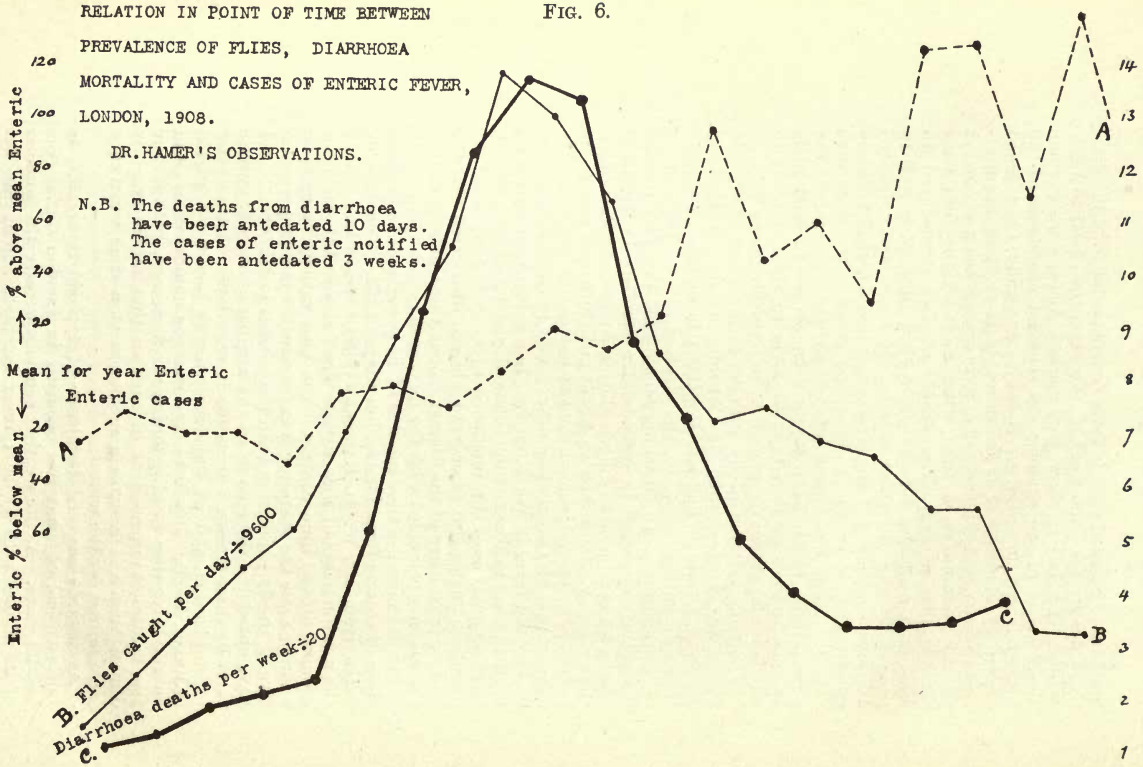
As regards seasonal incidence of typhoid fever 1908 is fairly typical of what has occurred in London during the last 20 years. As the weather becomes warmer the number of infections with typhoid fever increases and is not cut

RELATION IN POINT OF TIME BETWEEN PREVALENCE OF FLIES, DIARRHOEA MORTALITY AND CASES OF ENTERIC FEVER, LONDON, 1908.

DR. HAMER'S OBSERVATIONS.

FIG. 6.

N.B. The deaths from diarrhoea have been antedated 10 days. The cases of enteric notified have been antedated 3 weeks.



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short by the fall in temperature usually occurring in September, but reaches a maximum in October and November—that is, at a time when there are hardly any flies about. Whether, as Dr. Niven believes, increased fly prevalence is a factor in determining the increasing incidence in Manchester and London at the end of the summer, it seems to me impossible to say ; but, taking into account the circumstantial evidence against the fly, this may not unlikely be the case, but it is clear that other causes are operative and that epidemics of typhoid fever occur in these cities in the absence of flies.

This is in striking contrast to the observations in military camps both during the Spanish-American War and the Boer War. In both these instances, with the onset of cooler weather and the first frosty nights, the nuisance from flies was as once relieved and the cases of enteric fever diminished shortly afterwards.

Flies in Relation to Infantile Diarrhœa.

As the infective agent of infantile diarrhœa has not been identified, no direct evidence that flies do on occasion convey the germs of this disease is available. It is probable that more than one etiological factor for infantile diarrhœa exists. Different organisms have been found to be particularly prevalent in the stools in different epidemics in various localities. In America some of the epidemics have been associated with the presence of a dysentery bacillus (*B. Flexner*) in the stools—Wollstein (1903), Park (1903), Duval and Schorer (1903), Cordes (1903), Weaver and Tunnicliffe (1905). In other epidemics in America no dysentery bacilli were found, and an epidemic in Vienna investigated by Jehle and Charleton (1905) was not found to be associated with dysentery bacilli. Metchnikoff (1909) is of opinion that B. vulgare is the causal organism.

A search for evidence of a causal agent was conducted on a large scale by Morgan (1906, 1907, 1909) and his colleagues of the Lister Institute during the epidemic in London in the years 1905, 1906, 1907, and 1908. The search was restricted to aerobic bacilli which neither fermented lactose nor liquefied gelatin—i.e., to a group which includes the dysentery, typhoid and paratyphoid, and Gaertner bacilli. Stools and necropsy material were examined from several hundred cases of the disease, and from other children. A very large number of organisms were isolated and examined, but the only one whose prevalence was found to be related to infantile diarrhœa was a non-motile bacillus of the above group, which was peculiar in that it failed to ferment mannite. It is now generally known as Morgan's bacillus No. 1. This organism was not infrequently recovered from the organs in fatal

cases, and produced diarrhœa when fed to monkeys and young rats. It was rarely encountered in children not suffering from acute diarrhœa.

Morgan's bacillus has been found in flies captured from houses in which cases of diarrhœa occurred, but until its causal relation to the human disease is proven too much significance cannot be attributed to these observations.

We are, therefore, entirely dependent upon epidemiological facts in testing whether the belief in the dominant influence of the house fly in the occurrence of epidemics of infantile diarrhœa, a view which has been warmly espoused by many observers, is valid.

The Relations in Time Between Cases of Diarrhœa and Prevalence of Flies.

Unlike the case of typhoid fever which has just been discussed, the epidemics of infantile diarrhœa in towns exhibit a close time relation with fly prevalence. Epidemic diarrhœa of children does not occur except during that season of the year when flies are abundant and active, and, as will be seen on studying the charts, the relation between fly population and cases during the summer is so striking as to suggest something more than a mere accidental dependence upon the same phenomena.

The charts, Figs. 7, 8, 9, 10, and 11, show the relation of diarrhœa and fly prevalence in time. Figs. 7, 8, and 10 are derived from Dr. Hamer's observations in London in 1907, 1908, and 1909. Figs. 9 and 11 are constructed from Dr. Niven's (1910) observations in Manchester in 1904 and 1906. I have selected these particular years from the Manchester data because they represent what happened in warm summers in which the number of cases was considerable.

The charts have undergone some manipulation at my hands. I have antedated the deaths by ten days, which, according to Dr. Niven's observations, represents the average period intervening between onset and death. They ought, no doubt, to be antedated further to include the incubation period, but I have no data to determine what this should be. In the case of Dr. Hamer's observations I have summed his tri-weekly observations and plotted the fly catch for the whole week. In this way I have eliminated most of the irregularities and obtained smoother curves. I have also added the weekly mean temperature for London for the period comprised by Dr. Hamer's observations, and in Fig. 8 for about two months previously.

The procedure adopted by Dr. Niven and Dr. Hamer to obtain data regarding fly prevalence was common in all cases. The number of flies caught on sticky paper or entrapped in a series of domestic dwellings, generally in neighbourhoods inhabited by poor people, were recorded

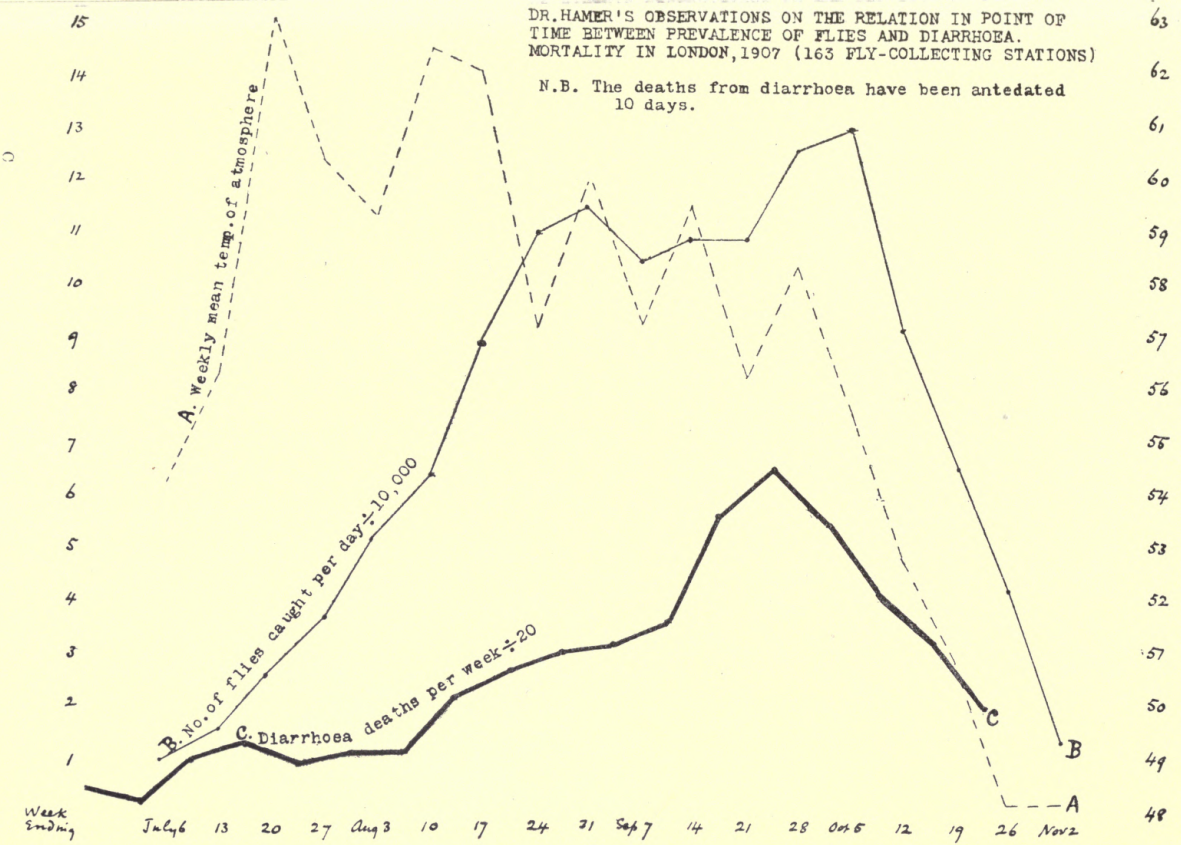

DR. HAMER'S OBSERVATIONS ON THE RELATION IN POINT OF TIME BETWEEN PREVALENCE OF FLIES AND DIARRHOEA. MORTALITY IN LONDON, 1907 (163 FLY-COLLECTING STATIONS)
N.B. The deaths from diarrhoea have been antedated 10 days.
A. Weekly mean temp. of atmosphere
B. No. of flies caught per day ÷ 10,000
C. Diarrhoea deaths per week ÷ 20
Week Ending
July 6 13 20 27 Aug 3 10 17 24 31 Sept 7 14 21 28 Oct 5 12 19 26 Nov 2
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
63 62 61 60 59 58 57 56 55 54 53 52 51 50 49 48

FIG. 8.

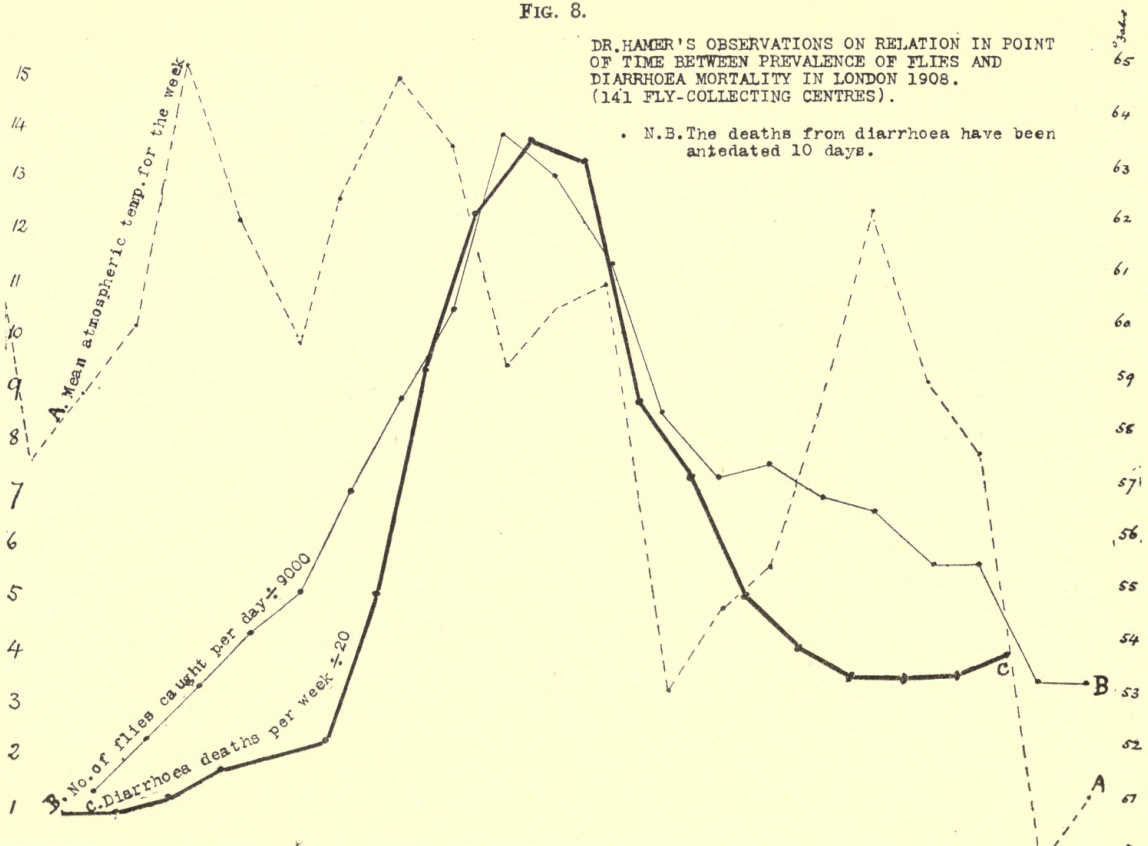
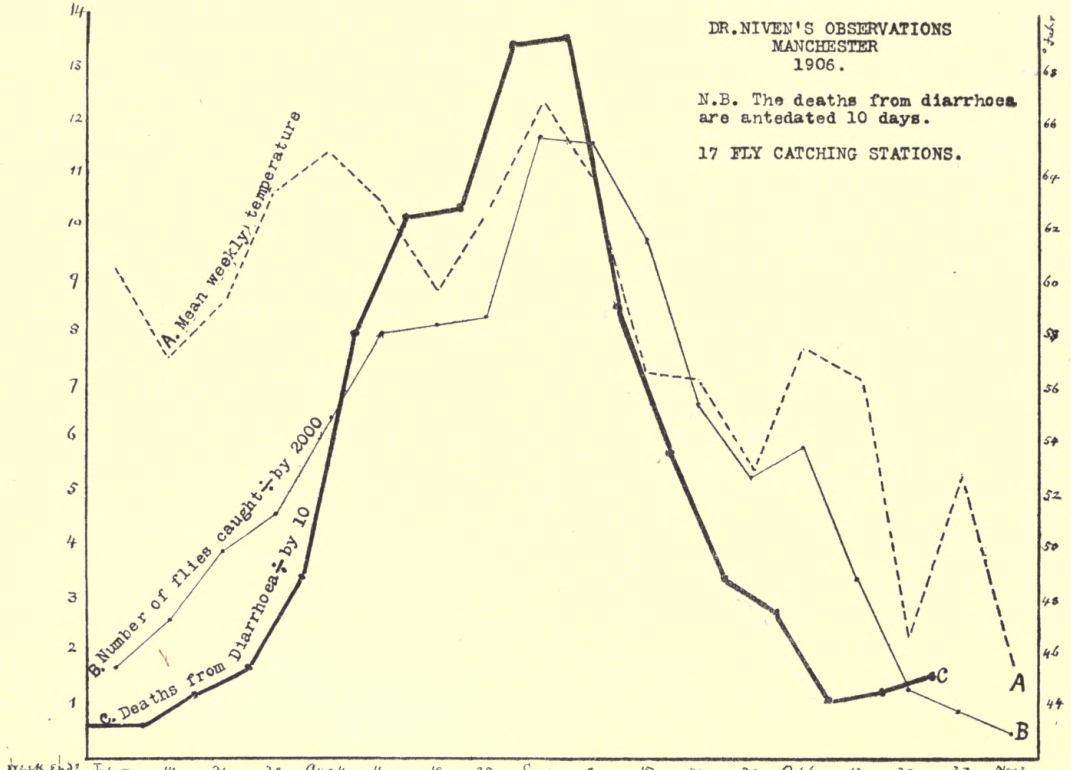

DR. HAMER'S OBSERVATIONS ON RELATION IN POINT OF TIME BETWEEN PREVALENCE OF FLIES AND DIARRHOEA MORTALITY IN LONDON 1908. (141 FLY-COLLECTING CENTRES).
N.B. The deaths from diarrhoea have been antedated 10 days.
A. Mean atmospheric temp. for the week
B. No. of flies caught per day ÷ 9000
C. Diarrhoea deaths per week ÷ 20
A
B
C

FIG. 9.


DR. NIVEN'S OBSERVATIONS
MANCHESTER
1906.
N.B. The deaths from diarrhoea are antedated 10 days.
17 FLY CATCHING STATIONS.
A. Mean weekly temperature
B. Number of flies caught ÷ by 2000
C. Deaths from diarrhoea ÷ by 10
WEEK ENDS
July 7
14
21
28
Aug 4
11
18
25
Sept 1
8
15
22
29
Oct 6
13
20
27
Nov 3
°Fahr.

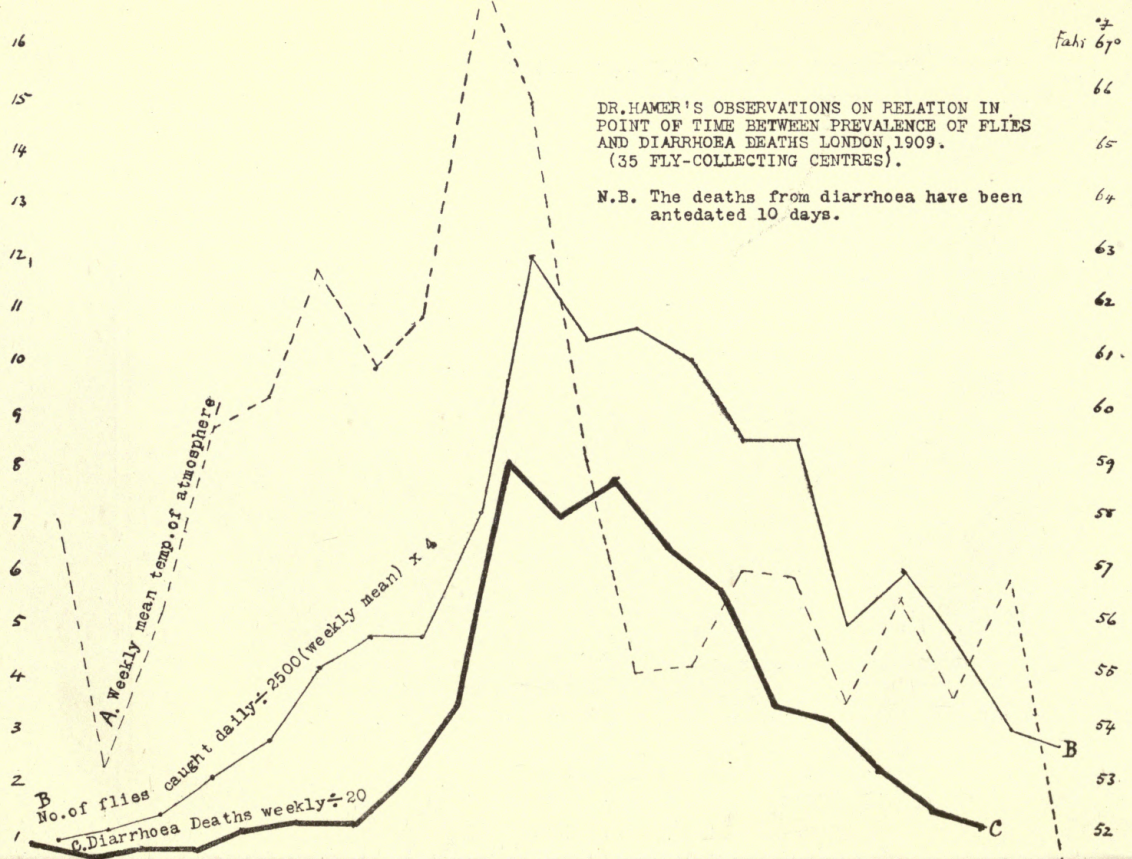
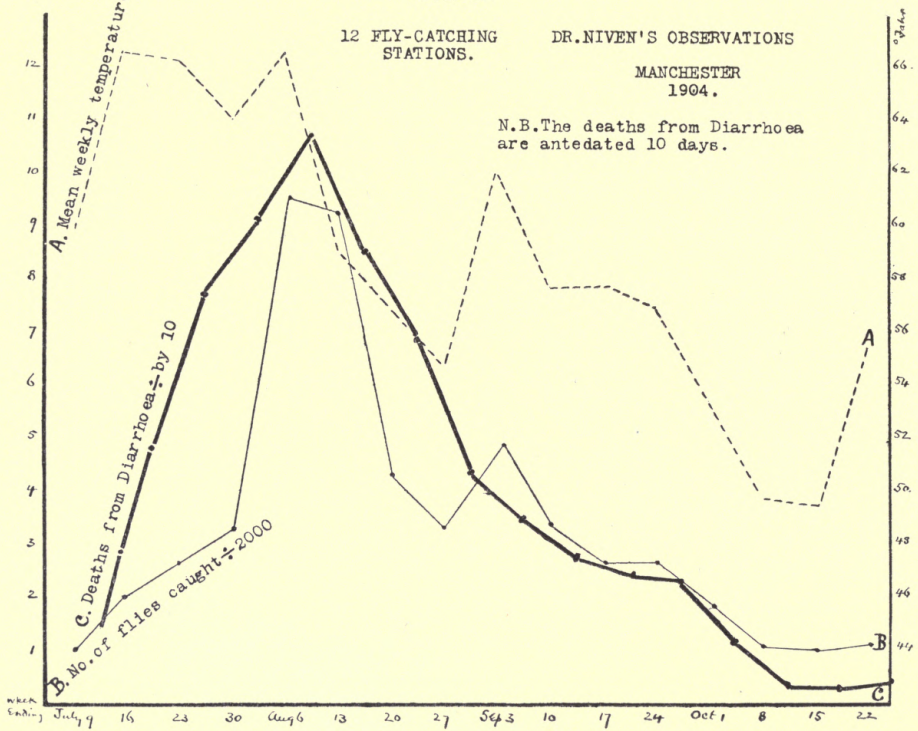

DR. HAMER'S OBSERVATIONS ON RELATION IN POINT OF TIME BETWEEN PREVALENCE OF FLIES AND DIARRHOEA DEATHS LONDON, 1909.
(35 FLY-COLLECTING CENTRES).
N.B. The deaths from diarrhoea have been antedated 10 days.
A. Weekly mean temp. of atmosphere
B No. of flies caught daily ÷ 2500 (weekly mean) x 4
C. Diarrhoea Deaths weekly ÷ 20
Fahr
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
67°
66
65
64
63
62
61
60
59
58
57
56
55
54
53
52
B
C

FIG. 11.


12 FLY-CATCHING STATIONS.
DR. NIVEN'S OBSERVATIONS
MANCHESTER
1904.
N.B. The deaths from Diarrhoea are antedated 10 days.
A. Mean weekly temperature
C. Deaths from Diarrhoea ÷ by 10
B. No. of flies caught ÷ 2000
A
B
C
WEEK ending July 9 16 23 30 Aug 6 13 20 27 Sept 3 10 17 24 Oct 1 8 15 22

every two or three days. This estimate of the prevalence of flies, together with the deaths from diarrhœa, were then plotted as ordinates against weeks as abscissæ. Dr. Niven's observations extend over five years, and refer to several districts in Manchester. Dr. Hamer's organisation for the capture of flies was on a larger scale, and his observations were made at various parts of London during 1907, 1908, and 1909, mostly in the neighbourhood of refuse and manure depôts where flies are bred. Another excellent series of observations was made by Dr. R. Dudfield (1912) in Paddington during the summer of 1911. It concerns a smaller number of cases, but this enabled a more intensive study of many factors contributing to the epidemic to be made.

The first point brought out by all these observations is the dependence of both the number of flies and the epidemic upon the cumulative effect of previous warm weather—as, for instance, is indicated by the earth temperature 4 feet below the surface—a fact to which attention was first drawn by Ballard (1889). The curve for flies rises first, followed soon by that for cases. The latter is longer in getting going; this is particularly marked in the cool summer of 1907. Both flies and cases reach their maxima about the same time. In 1907 the number of cases is diminishing, whilst flies are still on the increase. In 1908 and 1909 both curves decline together, but that for flies more gradually.

A notable feature of the curve is that the same fly population which is accompanied by a rise in the number of cases in early August corresponds with a fall in early September. This fact has been quite properly emphasised by the critics of those advocating the importance of flies.

If we propose to regard the time relations of fly prevalence and diarrhœa cases as more than an interesting coincidence, we must find a satisfactory explanation for the above facts.

Possible Explanations of Dependence of Diarrhœa Epidemics upon the Accumulative Effect of Temperature.

The reason why the number of flies is dependent upon this factor is obviously because the generation time (cycle from egg to egg) varies with temperature and requires three weeks or upwards in our climate. Months of warm weather are, therefore, required to produce any multitude of flies from the few surviving the winter.

Why the epidemic should exhibit this dependence is not obvious. Not knowing the etiology of diarrhœa, we must assume some sort of infective agent. From analogy with typhoid fever, cholera, acute food poisoning, and dysentery we will suppose that we have to deal with some form of bacterium growing in the outside world

with which our ailments might become infected. In this case, would the dose of infection be dependent upon the accumulated effect of temperature during the previous three months? Assuredly not. The generation time of bacteria is so short—in the case of bacillus coli it is 1 hour at 20° C. and ½ hour at 30°—that the number present at any moment is to all intents and purposes dependent only upon the mean temperature during the last few days. To take a homely illustration, whether one's milk sours does not depend upon the temperature last month, but last night.

In the accompanying table (II.) I have set out the rate of multiplication of *B. coli* at 20° C., and that of flies inside a

TABLE II.—*Showing the Rate of Multiplication (Maximum Observed) of House Fly and B. Coli.*

Days.	House fly August–September, 1907. Brighton.			B. coli commune 20° C.
0	1 (female).			1
	1st gen.	2nd gen.	3rd gen.	
1	—	—	—	10^{7} (10,000,000)
2	—	—	—	10^{14}
5	—	—	—	10^{3}
10	—	—	—	10^{70}
20	100	—	—	—
30	100	—	—	10^{720}
40	100	5000	—	—
50	100	5000	—	—
60	—	5000	125,000	10^{1440}

house during a summer in England. You will observe that one female fly might under these conditions possess 150,000 progeny in 60 days, but the bacteria derived from one organism become innumerable in two days. Unless, therefore, the effect of two months' summer weather be to change the nature of the organism so as to enhance its virulence, it is quite impossible to account for this striking characteristic of the epidemic by chance contamination of food-supply by pathogenic bacteria. In a state of innocence regarding the etiology of the disease we have no means of knowing whether any change occurs in virulence under the influence of continued hot weather, but it is just conceivable.

On the other hand, we have excellent *a priori* reasons for supposing that flies could transmit the infective agent of diarrhœa. Anyone familiar with the domestic ménage of the average working man on a hot summer day, with the baby sick with diarrhœa and other small children to care for, must realise that the opportunities afforded for fly transmission are adequate enough.

It seems to me, therefore, that before abandoning the view that diarrhœa is a bacterial infection or making the gratuitous assumption that a long spell of warm weather is necessary to awaken pathogenicity, one must carefully examine the adequacy of the hypothesis that the dependence of the epidemic on accumulated temperature is to be accounted for by the operation of this factor upon the means of transmission.

We will now see whether this interpretation fits the rest of the facts. The greater steepness of the rise of the diarrhœa curve is consistent with this view, for at first the opportunities for a fly to transmit the infection are small, but as the cases increase opportunities increase likewise. As has been pointed out by Hamer and Peters, if variation in the number of fly transmitters of an infective agent existing in the stools of patients were the sole factor concerned, the curve for diarrhœa cases should shoot up beyond and come down later and more slowly than that representing the number of flies, because the opportunities afforded to flies to pick up the infective agent are increasing *pari passu* with the development of the epidemic. This is, however, not what happens. On the contrary, the epidemic is arrested while flies are numerous, and declines more quickly than the fly population. We are therefore confronted with the question :

What Arrests the Rise in the Epidemic Wave?

Exhaustion of susceptible material has been suggested. This obviously plays a part in every epidemic, and the observations of Peters (1910) in Mansfield—where, under similar conditions, in one section of the town the epidemic was nearly finished, whilst in another it was beginning—afford a demonstration that it is a factor of importance. As, however, small epidemics in cool summers exhibit the same feature it cannot be entirely responsible for the arrest.

Another factor which must be taken into account is the atmospheric temperature at the time. A glance at the charts, Figs. 7, 8, 9, 10, and 11, in which the weekly mean temperature is also shown, suggests that this is playing an important part, for the decline of the epidemic occurs immediately upon a considerable drop in mean temperature and a diminution of fly prevalence follows shortly afterwards.

The influence of atmospheric temperature appears to be more marked upon the number of infections than upon the

number of flies. Whereas in London, 1908 and 1909, following shortly upon the colder weather, both curves drop in a remarkably similar fashion, in the small epidemic of 1907 the number of flies still remains up and even increasing, whilst the epidemic is rapidly disappearing. The same general facts emerge from the Manchester observations. We might invoke the assistance of coincident exhaustion of susceptible material, or diminished activity of flies, although still numerically sufficient, in explanation of this. They may, indeed, be operative, but I think that a completely satisfactory interpretation of the above facts and also of the fact that, with a given number of flies, the epidemic wave is ascending during the early weeks of an epidemic, and subsiding a month or six weeks later, is afforded by taking into account the influence of the variations in atmospheric temperature upon the rate of multiplication of the infective agent. Regard for a moment Fig. 8, the chart expressing the results of Dr. Hamer's observations in London, 1908. Take the weeks ending August 25th and Sept. 12th, in which approximately the same number of flies were caught. The mean temperature for the former week was 62·6° F., for the latter 54·8°. In the meantime it had been down to 53°.

The mean atmospheric temperature is a factor to which insufficient attention has been given, since the origin of the epidemic showed but small relation to it. It is capable, however, of explaining why the epidemic wave rises in August and falls in September, although the number of flies may be the same. Assuming, for the sake of argument, that some form of bacterial infection is the etiological factor in infantile diarrhœa, it would be in accordance with general experience to suppose that the chance of infection is determined by the quantity of the infecting agent imbibed. This will depend upon the multiplication which has taken place on the infected medium prior to ingestion ; this in turn is a function of the temperature at which the milk or other foodstuff has been kept.

The temperature coefficient of bacterial multiplication is not higher than that governing ordinary chemical processes—viz., two to three times for 10° C., but as bacterial multiplication proceeds logarithmically a comparatively small change in rate is sufficient to produce a large difference in the number of organisms contained in, say, an infected milk, if an interval of some hours elapse between inoculation and drinking. Thus if n bacilli coli be inoculated with milk at 60° and 70° F. respectively, the number after 12 hours will be $126n$ and $4000n$ respectively.[3]

[3] For the observations on which this calculation is based see Dr. Janet E. Lane-Claypon's paper Multiplication of Bacteria and the Influence of Temperature Thereon, Journal of Hygiene, vol. ix., 1909, p. 239.

Factors Contributing to Decline of Epidemic.

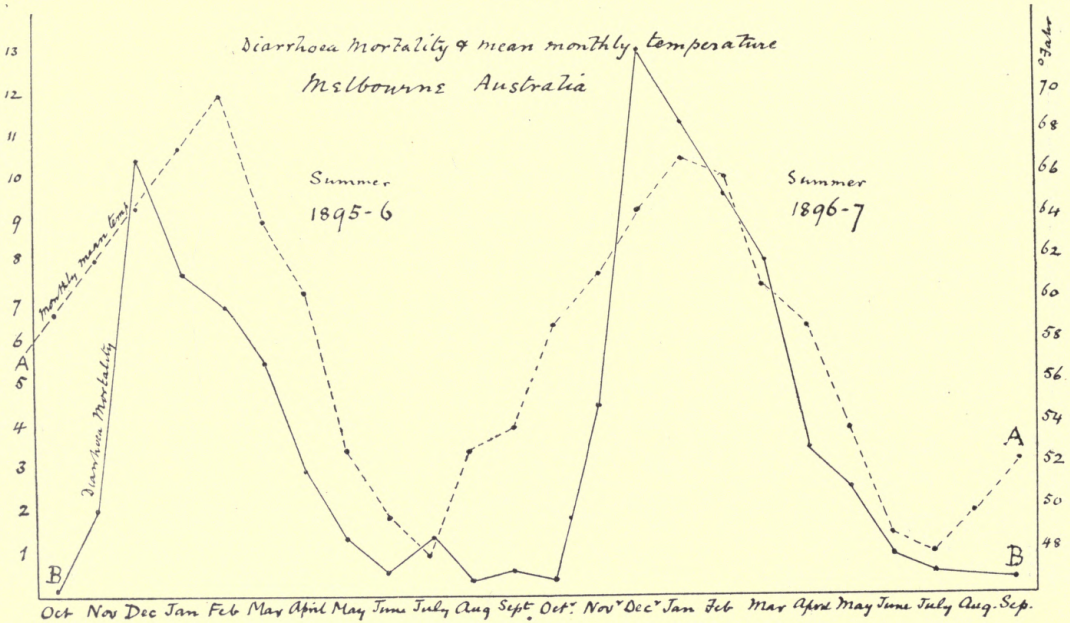
We have, then, two factors which may contribute in varying degree to decline of the epidemic : 1. A fall in temperature diminishing (*a*) the activity and number of supposed transmitters ; (*b*) the dose of infection which the child ingests owing to the effect upon the rate of multiplication of the infective agent. 2. The exhaustion of the more susceptible individuals.

Sometimes one, sometimes another, of the above factors appears to predominate. For instance, we have the fact, to which attention was drawn by Peters (1909), that in a much hotter climate, such as Australia, the epidemic often declines notwithstanding the fact that the temperature may continue to rise for several weeks. In Fig. 12 I have plotted from a paper by Stawell (1899) the monthly mean temperature and monthly diarrhœa mortality in Melbourne for the years 1895–96. In this city, where winter and summer succeed one another without the long intervening periods we have here, the epidemic lasts for six months instead of six weeks. It will be noticed that in 1895 the temperature continued to mount for two months after the summit of the epidemic. In this case the decline cannot be due to diminished dose of the poison owing to slower rate of bacterial growth, but must be attributed to exhaustion of susceptible individuals or to the effect upon the presumed transmitting agents, the flies. In the absence of definite quantitative observations I cannot speak dogmatically, but as far as my memory serves me I think the number of flies diminishes in Melbourne, as it does in Washington, during the hot weather. A monthly mean temperature of 70° in Melbourne indicates that there were a good many days with a maximum shade temperature of over 100°, which in that locality is associated with extremely dry north winds. Such meteorological conditions are very fatal to flies both in the larval and imago stage. On hot wind days flies have to seek shelter out of the sun or they rapidly become desiccated. For the same reason they succumb on an exposed window pane, and large numbers of dead flies accumulate on the window frame.

Relation between Fly-prevalence and Diarrhœa Cases in Space.

No quantitative observations upon the relation between number of flies and the distribution of cases of infantile diarrhœa have, as far I am aware, been made, but I may mention a few impressions by different observers for what they are worth. Nash (1909), who, whilst medical officer of health for Southend, made during 1904 spot maps of the epidemic there, says : "The great majority of the deaths from diarrhœa were shown to have occurred in streets in

FIG. 12.


Diarrhoea Mortality & mean monthly temperature
Melbourne Australia
Summer
1895-6
Summer
1896-7
monthly mean temp.
Diarrhoea Mortality
A
B
A
B
13
12
11
10
9
8
7
6
5
4
3
2
1
70
68
66
64
62
60
58
56
54
52
50
48
Oct Nov Dec Jan Feb Mar April May June July Aug Sept. Oct. Nov. Dec. Jan Feb Mar April May June July Aug. Sep.

proximity to brickfields in which were deposited daily some 30 tons of fresh house refuse, which bred incalculable numbers of flies" directly the meteorological or seasonal conditions became favourable for their development.

Dr. J. Niven (1910, p. 45) is of opinion that the close correspondence between flies and cases of fatal diarrhœa receives a general support from the diarrhœa history of sanitary subdivisions of Manchester, and that the few facts available for the study of correspondence of flies and fatal cases in different subdivisions (Manchester) in the course of the same year also lend support. No other explanation, in his view, even approximately meets the case.

Peters (1910), in his very exhaustive study of the epidemic in Mansfield in 1908, paid especial attention to the possible part played by flies. From an analysis of his observations he, I think justly, came to the conclusion that the evidence pointed to the fact that, whatever part they might play as carriers from an infected household to a neighbour, flies did not bring infection with them from the manure heaps where they had been bred. Peters constantly noted that the individual seemed to be a source of infection to the neighbours adjacent to the house, within the precincts of which his excreta, if infectious, would most likely be deposited. This he points out could be most readily explained by the supposition that flies were the agents of dissemination of the infection, but from the frequent want of correspondence in different localities between numbers of flies and amount of diarrhœa, he finds no support for this hypothesis from the distribution in space of flies and cases.

I doubt very much whether any evidence of great value could be obtained upon this point. Even supposing it to be true that fly carriage is of first importance, I should expect that if all the facts were known a much higher correlation would be discovered between diarrhœa and carelessness with regard to disposal of excreta and protection of food from the visitation of flies than between diarrhœa and fly prevalence.

Many of the facts which I have brought forward merely indicate some form of infective agent, and do not necessitate recourse to the hypothesis that carriage by flies dominates the situation. I would, however, point out: (1) that the fly-carrier hypothesis is the only one which offers a satisfactory interpretation of the extraordinary dependence of the epidemic upon the accumulated effect of temperature; (2) that it offers a ready explanation of the spread of infection to neighbouring children who have no direct personal contact with the patient; (3) that the peculiarities of the relation in time between fly prevalence and the epidemic in different localities are *not* inconsistent with the view that fly carriage is essential to epidemicity.

No other interpretation which is, so far, forthcoming is nearly so satisfactory, and it is at least worthy to guide in the meantime our efforts at prevention.

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LECTURE II.

The Transmission of Plague by Fleas.

Mr. President and Gentlemen,—May I remind you that bubonic plague is not an infectious disease? The patient is a negligible source of danger to his surroundings, provided he does not develop a secondary pneumonia. The reason is that even if the excreta do contain some plague bacilli, there is no mechanism available to convey them into a second human being, as pest is not easily contracted by feeding. From an epidemiological point of view bubonic plague must be regarded as a disease of rats, in which under suitable conditions the infection spreads from rat to man.

It would be impossible for me to put before you this afternoon the mass of evidence for the above statements. I have already surveyed it in opening the discussion on the spread of plague at the meeting of the British Medical Association at Birmingham in 1911 (Martin, 1911), and, moreover, it is now well known.

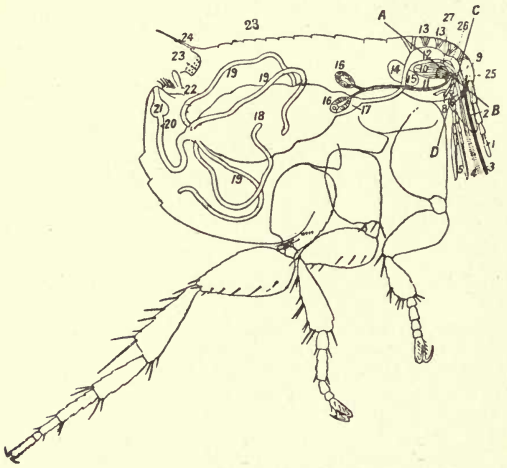
It was difficult to explain how the bacillus was transferred to man from the rat, especially as man to man infection had been shown to be negligible. On epidemiological grounds Ogata (1897), Simond (1898), and Ashburton Thompson (1900) came to the conclusion that the agent must be some form of insect, and for various reasons choice fell upon the flea. You will naturally inquire why, if the flea is to be considered an agent of transmission from rat to man, does it not transmit from man to man? The answer is quite satisfactory, but I will, with your permission, postpone it until we have considered the case for carriage from rat to man.

If the blood of the animal contain a sufficiency of plague bacilli, some will obviously be taken in by a flea whilst feeding, and Ogata (1897) found that crushed fleas taken from a plague-infected rat produced the disease when injected into mice. This experiment was repeated with success by Simond (1898) and Tidswell (1900).

The Mechanism by Means of which the Flea might Infect a Healthy Animal.[4]

The blood is sucked up from the wound made by the pricker. This structure is composed of three parts, the epi-

FIG. 13.



Diagrammatic mesial sectional view of *Xenopsylla cheopis* (from Report of Commission for Investigation of Plague). 1, Maxillary palp. 2, Maxilla. 3, Epipharynx. 4, Mandibles. 5, Labium. 6, Undivided portion of labium. 7, Basal portion of labium. 8, Basal portion of mandibles. 9, Salivary pump. 10, Hypopharynx. 11, Salivary duct. 12, Aspiratory pharynx. 13, Muscles operating the aspiratory pharynx. 14, Supraœsophageal ganglion. 15, Subœsophageal ganglion. 16, Salivary glands. 17, Gizzard. 18, Stomach. 19, Malpighian tubules. 20, Rectum. 21, Rectal glands. 22, Claspers. 23, Pygidium. 24, Antepygidial bristle. 25, Termination of dorsal contour of epipharynx. 26. Mouth. 27, Ligament.

pharynx and the two mandibles (Fig. 14 (5, 10, 10′)). The apposition of the three forms a fine tube, shown in cross section in Fig. 15, up which the blood is drawn and passed

[4] In dealing with the agency of fleas in the spread of plague, I shall draw largely upon the work accomplished during the last few years by the Commission for the Investigation of Plague in India, with which I have had the honour to be associated. The reports of the Commission have been published as special numbers of the Journal of Hygiene, 1906 to 1912.

down the gullet into the stomach by successive waves of contraction from before backwards of the muscles actuating the chitinous pharynx (Fig. 14). The stomach is a

FIG. 14.

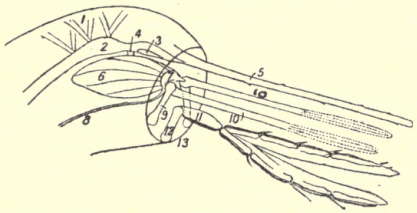


Diagram of the mouth parts of the flea (from Report of Commission for Investigation of Plague). 1, Muscles operating aspiratory pharynx. 2, Aspiratory pharynx. 3, Mouth. 4, Ligament, 5, Epipharynx. 6, Hypopharynx and muscles operating salivary pump. 7, Salivary pump. 8, Salivary duct. 9, Basal element of mandible. 10, Mandible. 11, Labium. 12, Basal element of labium. 13, Perioral ring. The thickness of the epipharynx and mandibles and the distance apart of these three instruments is exaggerated. In reality they are apposed and form together the channel through which the blood is sucked.

FIG. 15.

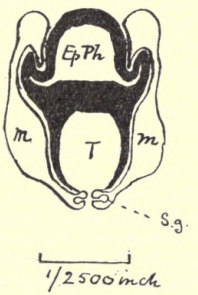


Diagram of transverse section of the piercing organ of the flea. EP PH, The black part beneath these letters is the epipharynx. M, Mandibles. T, Tube through which blood is sucked. SG, Salivary gland.

pear-shaped organ occupying a considerable part of the abdomen of the insect. The internal economy of a flea and the arrangements of the mouth-parts may be gleaned

from the diagrams (Figs. 13, 14, and 15), which are borrowed from the reports of the Commission.

The average capacity of a rat flea's stomach was found by the Commission for the Investigation of Plague in India (Report 1907, p. 397) to be 0·5 c.mm., and the number of bacilli in the blood of a plague-infected rat before death anything up to 100,000,000 bacilli per cubic centimetre. If, therefore, a rat flea imbibed the blood of such a rat it would receive into its stomach 5000 germs.

Evidence of Multiplication of Bacilli in the Stomach of the Flea.

The Commission fed fleas on plague-infected rats until the death of the latter, and afterwards on healthy animals, a fresh animal being supplied each day. Each day a number of the fleas were dissected, and the stomach contents were examined as to the presence or absence of plague bacilli. In 5 to 30 per cent., according to the time of year, plague germs were found up to the sixth day, and in one instance on the twentieth day (Reports 1907, pp. 398–405). The bacilli were often present in immense numbers, far more numerous than ever seen in blood, and massed together as in a culture. We have good evidence in this observation that multiplication of plague bacilli may take place in the flea's stomach.

During the season of the year when the epidemic occurs the proportion of infected fleas for the first four days after removal from the plague rat was 43 per cent., on the sixth day there were 15 per cent., on the eighth day 16 per cent., and on the twelfth day 9 per cent. In the non-epidemic season only 5·2 per cent. were infected during the first six days.

The Distribution of Plague Bacilli in the Body of the Flea.

The blood on completion of the digestive process in the stomach passes into the rectum of the flea as a thick, slimy, dark-red mass, and appears at the anus as minute, dark red or black, tarry droplets. It was demonstrated by cultural and microscopical examination that the rectal contents were often crowded with plague bacilli.

Fleas, taken from plague rats at intervals varying from a few hours to several days, were dissected and the various parts of the body examined for the presence of bacilli. In not a single instance were any plague bacilli observed outside the organs already mentioned. No infection of the body cavity was seen, and, although particular attention was paid to the salivary glands, nothing at all resembling a plague bacillus was ever detected in them.

How the Flea may Transmit its Infection to the Healthy Animal.

Several methods of transmission are possible, such as (*a*) the animal eating the infected fleas ; (*b*) the mechanical conveyance of the bacilli by the pricker ; (*c*) the regurgitation of the stomach contents down the pricker ; (*d*) the deposition of the fæces on the skin, the bacilli being subsequently rubbed in by scratching.

This last method is the only one which has been proved capable of bringing about infection. A well-fed flea deposits a considerable amount of fæces in a surprisingly short time, and it was proved by both the Commission for the Investigation of Plague in India (Report 1907, p. 418) and Verjbitski (1904) that wounds made by the pricker might afford a sufficient avenue for the entrance of bacilli when liquid containing them was gently applied to recent bites.

Whilst, however, experiments have shown that infection may be brought about in this way, the possibility of infection by a regurgitation from the stomach preliminary to sucking blood cannot be excluded.

Proof that Plague is Carried from Animal to Animal by Fleas.

Simond (1898) infected one rat from another by placing them in a bottle together with 20 fleas. The second, uninfected, rat was enclosed in an iron box with a grating, so that the two animals could not come into contact.

Gauthier and Raybaud (1902–1903) repeated Simond's experiments under better controlled experimental conditions. They employed a cage, divided in the middle by two wire grills 2 cm. apart, placed in a glass jar. In one compartment was placed an inoculated white rat on which had been deposited a dozen fleas captured upon rats from ships in the harbour at Marseilles. When the inoculated animal died a healthy rat was placed in the second compartment, and after some hours had elapsed, during which the fleas transferred themselves from the dead to the living animal, the cadaver was removed. Gauthier and Raybaud succeeded five times in conveying the infection from one rat to another ; the number of negative experiments is not stated. An examination of the stomachs of the fleas found upon the septicæmic animals showed the presence of *B. pestis*. The fleas used in their early experiments were not identified. Tidswell (1903) made further attempts to convey plague from rat to rat by the agency of fleas, but was unable to do this.

Verjbitski (1904) carried out an extensive series of experiments on the flea-transmission of plague in St. Petersburg. He showed that the plague bacilli could be recovered from the stomach contents of fleas six days after they had fed on

plague rats, and that the fæces of such fleas contained the *B. pestis* for about the same time. He succeeded in infecting rats with fleas from diseased rats 15 times in 76 experiments. In each experiment 10 possibly infected fleas were allowed to feed on the rat. Verjbitski also made experiments similar to those of Gauthier and Raybaud described above, and out of 40 experiments, using 10 fleas apiece, infection was conveyed in 4.

Liston (1905) pointed out that the common flea infesting rats in India was not *Ceratophyllus fasciatus* or *Typhlopsylla musculi*, as in Europe, but a non-pectinated flea identified by Rothschild as *X. cheopis*. Liston observed multiplication of the plague bacillus in the stomach of this flea. Although his experiments on transmission, which were made by allowing fleas to bite first an animal suffering from plague and subsequently a healthy animal, were not successful, he brought forward much interesting and valuable circumstantial evidence in favour of the view that plague is epidemiologically thus spread. He showed that *X. cheopis* takes readily to another host — e.g., guinea-pigs and man — when rats are not available.

The possibility of the rat flea carrying plague from one rat to another was demonstrated in a considerable series of experiments by the Commission for the Investigation of Plague in India (Reports, 1906, pp. 435–50). A glass case was used containing two wire cages side by side, each standing in a tin tray which collected the urine. Both trays were filled with sand, in order to provide dryness and shelter for the fleas. Each cage was furnished with a lid through which the rats were introduced, and food and water given to them, and the whole apparatus was covered in with fine muslin to prevent the escape of the fleas. A rat placed in one of these wire cages could not come in contact with a rat in the other cage, nor with its urine or fæces.

The method of experiment is as follows. A plague-infected rat and a number of rat fleas were placed in one of the wire cages. After the rat died a fresh healthy rat was put into the other cage, the corpse of the infected rat being left in for 24 hours longer. Sixty-six experiments with English white rats and with Bombay wild rats were done in this way, with the result that 30 healthy rats contracted plague; fleas formed the only apparent means of transmission of the bacilli from rat to rat.

In order to exclude aërial infection a second series of experiments was carried out, in which fleas were taken from a rat which had died from plague and placed on a fresh rat in a clean flea-proof cage of similar construction to that already described, but containing only one wire cage. Out of 38 experiments 21 successful transmissions were obtained in this way.

The Importance of Flea Transmission in Epizootics.

The following experiments, which had as their object the determination of the relative importance of the Indian rat flea *X. cheopis*, and of actual close contact in the absence of fleas in the dissemination of plague from animal to animal, were carried out by the Commission (Reports 1906, pp. 450–67, 1907, pp. 421–36, 1910, pp. 315–35) in a series of small cabins, which were built especially for this purpose. In these animal houses plague-infected animals, rats or guinea-pigs, were kept in close contact with healthy animals. They ran about together in a confined space, and ate out of the same dishes. The plague-infected animals were allowed to die, and the corpses were not removed until some time after death. In some instances the concentration of infection was very great, in one case 21 infected animals being at one time in contact with 25 healthy ones. The cabins were never cleaned out, so that the animals ate food contaminated with the fæces and urine of their infected companions. In the experiments with rats, the healthy frequently ate the carcasses of the infected ones introduced.

Sixty-six series of experiments were carried out, each involving about 40 to 70 animals. In 35 experiments fleas were present and 31 were control experiments in which no fleas were introduced. In all the control experiments not one of the healthy animals contracted plague, whereas in those cases where fleas were present an epizootic occurred, varying in extent and rate of spread according to the number of fleas present.

Some interesting experiments (Reports 1906, p. 461) were also carried out in the animal houses that had been used for some of the previous experiments. Guinea-pigs and monkeys were introduced into them for one night. Some of the animals were in cages placed on the floor, and others in cages covered by fine muslin gauze, or surrounded by a layer of sticky fly-paper, 6 in. wide—that is, the simplest precautions were taken to exclude fleas. Of 13 unprotected monkeys six died, of protected none. Of 24 unprotected guinea-pigs 18 died, of protected none. The animal houses remained infective three weeks after the last animal had died from plague. This period corresponds with the maximum time fleas fed on a plague rat have been shown to remain infective when placed on a series of healthy animals.

Experiments in Plague Houses.

The Commission subsequently (Reports 1906, pp. 467–82, and 1907, pp. 436–46) repeated similar experiments in plague houses in Bombay. The infectivity of 142 houses

where cases had occurred or rats had died was tested by placing a guinea-pig there overnight. The guinea-pig was subsequently segregated, and in 31 cases it died from plague.

Experiments were made in which two similar animals—monkeys, guinea-pigs, or rats—the one protected by gauze or sticky paper, the other not protected, were placed in suspected houses. Of 92 experiments, 15 unprotected animals died, none of the protected.

On 96 occasions fleas taken off guinea-pigs which had spent the night in a suspected house were transferred to a healthy animal. In 26 cases the second animal died from plague, although not infrequently the guinea-pig from which they had been removed escaped infection. The conclusion that in a plague-infected house the infection is due to infected rat fleas, and not to an infection of the soil or the air, seems to me abundantly justified.

Fleas as the Agents of Transmission from Rat to Man.

In considering how far the results just detailed can be applied to man we enter at once upon less secure territory, because it is impossible to put conclusions to the test of experiment. The only measure of the correctness of such an interpretation is its adequacy to interpret all the known epidemiological facts concerning the spread of plague.

The justice of applying the results of these animal experiments has been severely criticised in several quarters, and particularly by Galli-Valerio (1907), on the ground that rat fleas do not bite man. It is true that, speaking generally, different animals harbour specific parasites; but the more we learn upon this subject the clearer it becomes that such specificity is not so sharply defined as was imagined, and that a particular flea, although commonly confined to a few hosts of allied species, may frequently be found in considerable numbers upon quite different animals. Moreover, it has become abundantly clear that a flea, although exhibiting a decided preference for one species, will, if hungry, betake itself to animals of widely different type in the absence of its proper host.

The common flea found on rats in India and other warm parts of the world [5] is *X. cheopis*. This flea is a non-combed species, and not unlike the human flea *Pulex irritans* in appearance. That *X. cheopis* readily feeds on man was observed by Tidswell (1903), Gauthier and Raybaud (1903), and Liston (1905). The Commission for the Investigation of Plague in India kept *X. cheopis* alive for four weeks upon an exclusively human diet, and my colleague, Mr. Bacot, has bred them for years on the same regimen.

[5] Distribution of rat fleas has recently been dealt with by Dr. Chick and myself in the Journal of Hygiene, vol. ii., p. 129, 1911.

With regard to the readiness with which *Ceratophyllus fasciatus*, the common rat flea in Europe, attacks man, considerable divergence of opinion has hitherto existed. According to Wagner (quoted by Tiraboschi 1904, p. 180), Tiraboschi (1904, p. 266), and Galli-Valerio (1907), this flea does not bite man. On the other hand, Gauthier and Raybaud (1903 and 1909), and McCoy and Mitzmain (1909) found that when hungry it fed on man with readiness.

Dr. Harriette Chick and I (1911) have made some hundreds of experiments on this question, and are at a loss to understand the negative conclusions arrived at by Tiraboschi and Galli-Valerio. Under the conditions of our experiments *Ceratophyllus fasciatus* fed upon man as readily as upon a rat. (Table III.) Nevertheless, it is doubtful whether

TABLE III.—*Showing Results of Feeding Experiments with Ceratophyllus Fasciatus.*

—	Subject.								Summary.	Rat.	Rabbit.
	C. J. M.	H.C.	A.M.	J. H. S.	H. Y.	G. F. P.	H. W. A.	S. R.			
Total number of experiments ...	161	118	39	33	52	51	40	23	517	101	32
Positive	106	65	30	12	36	25	19	15	308	59	23
Negative	55	53	9	21	16	26	21	8	209	42	9
Per cent. positive ...	65·8	55·1	76·9	36·4	69·2	49·0	47·5	65·2	59·6	58·4	71·9

Ceratophyllus fasciatus is attracted to man as readily as is *X. cheopis*. Compared with the latter, it is a poor jumper.

We also made 107 experiments with *Ctenopthalmus agyrtes*, a flea common on *Mus decumanus* in this country, when living in fields, ricks, or barns, and 122 experiments with the mouse-flea *Ctenopsylla musculi*. Under the conditions of the experiment the former would not bite man at all, and the latter only very occasionally. This latter experiment is interesting, because mice, although dying from plague, have not been found to be associated in the same way as rats with the origin of plague epidemics.

The Capability of Flea Transmission to Interpret the Epidemiological Facts Regarding Bubonic Plague.

(1) Poverty, dirt, storage of grain in the bedroom, accumulation of refuse, and insanitary conditions generally, have been shown to be effective in so far as they lead to the support of a large rat population in close association with human beings. All these conditions also increase the population of rat fleas, and man's accessibility to them.

(2) In 75 per cent. of cases the situation of the bubo is such that the bacillus must have obtained entry at some superficial area of the body. This is also consistent with infection by fleas.

(3) A number of instances have occurred during the last ten years in India in which the introduction into a distant village of the effects of a person dead from plague has been followed, after an interval of about a week, by mortality amongst the rats, and subsequently by an epidemic of plague. The same sequence has also taken place after the visit of an individual who had worked on resided in a house where some of the inmates had suffered from plague, although the stranger himself did not suffer from the disease. These observations are better explained on the assumption that the infection was transported in the bodies of fleas contained in the clothing or upon the person of the stranger than by any other suggestion that has been put forward, for at the earliest opportunity rat fleas would betake themselves to the rats, and could thereby start an epizootic. That such transmission of rat fleas does actually happen has been proved by the Commission for the Investigation of Plague in India, members of which frequently carried away rat fleas upon their persons and clothing when visiting native quarters in the course of their scientific duties.

(4) Perhaps the most striking feature of epidemics of bubonic plague is the marked seasonal prevalence of the disease amongst rats and amongst men. In places where it is endemic the epizootic followed by the epidemic starts at or about the same time each year, grows, declines, and finally more or less disappears. As one passes away from the Equator the plague season becomes later. In Bombay the height of the epidemic is in March, in Lahore in April, in Jhelum in May, in Rawal Pindi in June, and further north in July, August, and September. The epidemics of London in 1665, and of Marseilles in 1720, reached their maximum in September. The effect of latitude in determining the season when plague flourishes is analogous to that upon the flowering and seeding of a plant, and indicates dependence on some biological factor. Within the Tropics, where

temperature variation is less, and the seasons are determined by the prevailing winds and rainfall, the epidemic season is also well defined, but varies in different localities.

The seasonal incidence of plague is not due to any periodicity in the breeding of rats. In India, in localities where the latter was investigated, it bore no relation to the season when plague occurred. It was found by the Commission (Reports, 1908, p. 266, and 1910, pp. 446 and 483), however, that the epidemic season coincided with the period of greatest flea prevalence. In Bombay, Belgaum, Poona, and two Punjab villages the Commission undertook a census of rat fleas upon captured rats, in the course of which the fleas on 150,000 rats were recorded. In each case the observations extended over more than one year. The analysis of the figures showed a seasonal variation in the number of rat fleas in all the localities. The average number per rat varied in Bombay between 3 and 7, in Poona between 2 and 11, in the Punjab between 2 and 12, and in Belgaum between 1 and 17. The interesting point is that in all the places examined plague is epidemic when the average number of fleas is well above the mean, and the height of the epidemic corresponds fairly closely with the season of maximal flea prevalence. A similar seasonal variation in the prevalence of *X. cheopis* and correspondence between the maximum of these fleas and the epidemic period has been observed by Kitasato (1909) in Japan, Tidswell (1910) in Sydney, and by Gauthier and Raybaud (1910–11) at Marseilles, and by Andrew (1911) in Tongschang in Northern China. The incidence of the epidemic period in the season of greatest flea prevalence under such different climatic conditions as obtain in Bombay, the Punjab, Poona, Tongschang, and Marseilles is in itself suggestive, and, in view of the results of animal experiments already referred to, one is justified in believing that the most favourable time for the epidemic is largely determined by the seasonal prevalence of rat fleas.

(5) The rat-flea hypothesis also affords an interpretation of the fact that epidemics decline when the mean daily temperature passes 85° F. A mean temperature of 85° F. in India means also dry weather. Fleas, whether in the larval, pupal, or imago state, are rapidly killed off at this temperature unless associated with a high degree of humidity.

The Commission for the Investigation of Plague in India found that in Bombay the proportion of fleas which become infected, the time they remain infected, and the number of successful experiments on flea transmission was greatest during the winter months (Reports, 1907, pp. 197–204, 1908, pp. 510–15 and 529–38). An analysis of their results showed 67 per cent. successful transmissions when the

temperature was 73° to 78° F., against 14 per cent. successes when the temperature was 82° to 85° F. Transmission experiments were therefore carried out simultaneously at 70° and at 85° F., in suitable chambers, both upon rats and guinea-pigs. The results were consistent with previous experience. The possibility that the virulence of the bacillus might undergo some variation if grown at one or other temperature was examined by the Commission and excluded.

The claims of flea transmission to be the predominating mechanism of spread from rat to man may be briefly summarised as follows:—

1. The experimental evidence that plague is easily transmitted from animal to animal by rat fleas.

2. That in presence of fleas, the epizootic, if started, varies as regards severity and rate of progress with the number of fleas present and the season of the year, whereas all attempts to induce epizootics in the absence of fleas have failed.

3. That under natural conditions (experiments in plague houses, &c.) an animal can be protected from infection by any simple procedure which will exclude the visits of fleas.

4. The only discovered infection in plague houses resides in plague-infected fleas.

5. The rat fleas *X. cheopis* and *Ceratophyllus fasciatus* readily bite man.

6. The conclusions drawn from animal experiments, when applied to the problem of the spread of plague amongst human beings, afford a reasonable interpretation of every cardinal epidemiological fact.

The Part taken by the Human Flea.

It is possible to transmit plague experimentally by means of *P. irritans*. Nevertheless, the direct transmission of the disease from man to man cannot, at the present time, be of frequent occurrence, or we should have evidence of direct infection instead of dependence upon the epizootic.

The reason why the human flea is ineffective is because in human cases the average degree of septicæmia before death is so much less than in rats that the chance of a flea imbibing even a single bacillus is small. A variation of the plague bacillus in the direction of greater infectivity, with perhaps diminished toxicity leading to a higher degree of septicæmia in man, would permit of direct transmission by human fleas. Bubonic plague would then be independent of the rat, and spread directly from man to man. For

several reasons it seems to me not improbable that this may have happened in the plague of the Middle Ages.

Other Diseases Transmitted by Insects.

Three other diseases which can be transmitted by insects —typhus, relapsing fever, and poliomyelitis—must be mentioned, although I am not sure that I am justified in including any of them under the heading "bacterial." The infective agent in typhus has so far not been isolated, but it is ascertained that it is an organism capable of propagation, for Nicolle (1910) and Wilder (1911) have succeeded in carrying the disease through a number of generations of monkeys by inoculating them with 1 to 5 c.c. of blood or serum from an infected animal. The organism is held back by Berkefeld and porcelain filters. It is therefore free in the blood and of some considerable size.

Relapsing fever is caused by a spirochæte, and there is considerable difference of opinion as to whether spirochætes should be classed amongst the bacteria or protozoa.

The infective agent of poliomyelitis is a minute invisible organism which passes readily through a porcelain filter, so that it escapes the clutches of the systematist altogether.

The Transmission of Typhus Fever by Lice.

Typhus is a disease associated with poverty and dirtiness. It occurs in temperate climates and mostly in the winter and spring. In warm climates it is uncommon. In Mexico, where it still flourishes amongst the poor Indians and half-caste population, it is confined to the central plateau 4000 to 10,000 feet above the level of the sea, and does not affect the population of the lower hot country, although cases are frequently introduced from the higher lands.

Typhus has been shown to be capable of transmission by the agency of body lice, *Pediculus vestimenti*, by Nicolle, Compte, and Conseil (1909), and by Ricketts and Wilder (Wilder, 1911).

The Bionomics of Lice and the Mechanism by means of which they might Carry Infection.

The life-history of the body louse has recently been studied by Warburton (1909), to whom and to my colleague, Mr. Bacot, I am indebted for most of the following facts on the subject. Unlike fleas, lice have no grub stage. The eggs take one to five weeks or longer to incubate, according to temperature. The young louse when just hatched is a small edition of the parent and sucks blood at the earliest opportunity. It is,

however, not sexually mature; three moults occur, in about 14 days its growth is complete, and the insect is sexually mature. The females lay 100–200 eggs. Lice, especially when young, are delicate creatures. They are voracious feeders, and must be fed at frequent intervals. They, as a rule, are unable to withstand starvation for more than two days. They are very sensitive to heat and drying, and soon succumb at temperatures above 25° C., unless the air be kept nearly saturated with moisture. They live in clothing and bedding, and feed several times in the 24 hours if opportunity be given. The optimum condition for their development occurs in the case of those persons who seldom wash their clothing or change it for sleeping.

The general arrangement of the alimentary canal may be seen in Fig. 16, which also shows the sac in the floor of the mouth which contains the piercing organ. The four salivary ducts (two only of which are shown) open into the base of this sac. The pharynx is a chitinous organ which collapses by its elasticity, and suction is produced by the contraction of the muscles (*m.*) attached to its dorsal surface and the chitinous skeleton of the cranium. The blood is forced into the stomach by the relaxation in order of these muscles from before backwards. The stomach or crop is a capacious organ with two lateral diverticula from its anterior end.

The body louse obtains its nourishment entirely by sucking blood. It is provided with penetrating instruments, the apposition of which forms a canal through which the blood is pumped into the stomach by a pharyngeal pump similar to that of the flea. These piercing instruments are not permanently exterior to the head and carried tucked away in a labium as in fleas and bugs, but, as described by Pawlovsky (1906), the apparatus is retractile and contained in a special pocket in the floor of the mouth, Fig. 16. The anterior part of the mouth is provided with a ring of hooklets, which is everted when the pricker is thrust out. (Fig. 17, B, *h.*) When the insect feeds the tubular "pricker" (*p.*) is protruded through the mouth and penetrates the skin of the host, and the hooklets serve to attach the mouth to the skin.

The exact way in which the sucking tube is built up is not quite clear, but from preparations made by my colleagues, Mr. Bacot and Dr. Rowland,[6] the arrangement of these parts appears to be as follows. Three elements enter into the formation of the "pricker," each of which is bifurcated at its base (see Fig. 17, A and B). From the dorsal and ventral aspects of two of these parts, just anterior to their bifur-

[6] I am greatly indebted to Mr. Bacot and Dr. Rowland, not only for lending me specimens of the mouth parts of the louse, but also for their kindness in making fresh dissections for the purpose of this lecture. The mechanism of the sucking apparatus of the louse is much more difficult to comprehend than that of the flea or bug, and the description given merely represents the conclusions I have been able to arrive at without a prolonged study of the intricate arrangement of the organ

cation, a chitinous expansion is given off which runs forward and embraces the finer piercing organs (Fig. 17, A and B, *Ch*). The two together form a sheath round the basal portions of the piercing organs.

The relation of the three elements to one another and how the sucking tube is formed may be seen from Fig. 17, C, which represents a transverse section in the neighbourhood of the line *x-y* in Fig. 17, A. *Ch.* is the chitinous sheath, *a* the dorsal element which we may call the stylet, *b* the median, and *c* the ventral element. The interlocking of the lateral chitinous expansion of *b* and *c* forms the canal (*s.t.*) up which blood is sucked.

FIG. 16.

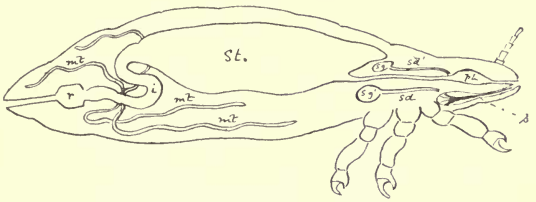
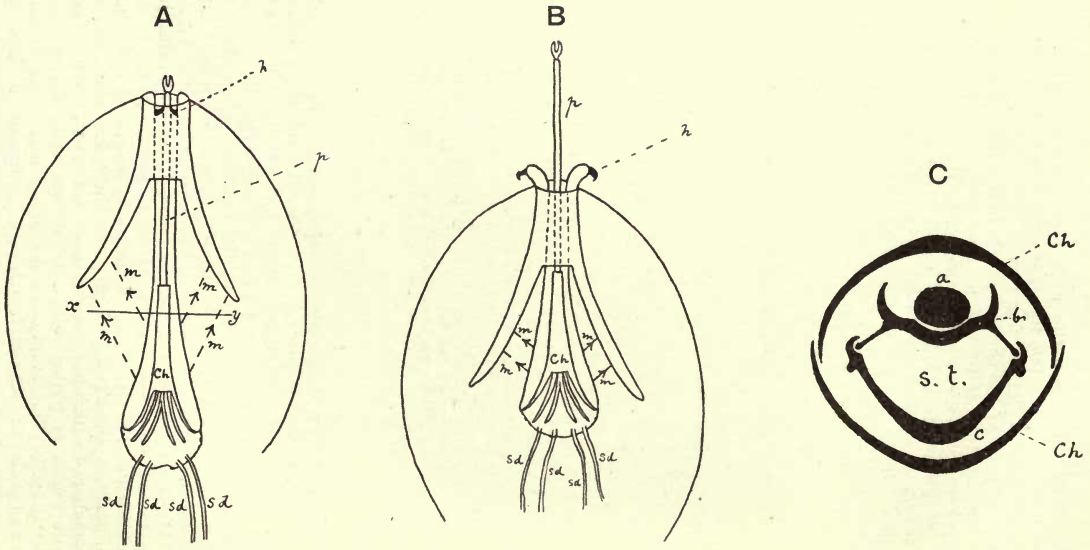


Diagram of the alimentary canal and mouth parts of the louse (Pediculus vestimenti), constructed from dissections by Mr. Bacot. The precise termination of the ducts of the two pairs of salivary glands is at present uncertain, but they can be traced into the base of the sac. PH, Pharyngeal pump. SG, Salivary gland. SD, Salivary duct. P, Pricker. ST, Stomach. I, Intestine. R, Rectum. MT, Malpighian tubes.

Fig. 17, A, is a diagrammatic representation of the head of a louse with the pricker retracted, B with the pricker extruded; *p.* is the "pricker" made up by the apposition of the three parts mentioned above. Anteriorly these pass through a tunnel in the substantial chitinous piece shaped like an inverted Y, which apparently also forms a skeletal framework for the attachment of the muscles (*m.*, Fig. 17, A and B) which pull the whole organ forward. *Ch.* is the sheath covering the basal portion of the piercing parts. At the base the bifurcation of the three elements is seen, and also the four salivary ducts (*s.d.*) which enter there, but the precise connexion of which has not yet been made out. When the whole organ is pulled forwards it not only drives out the "pricker" but evaginates the lining membrane of the sac and everts the ring of hooklets (*h.*), whereby the head is anchored to the epidermis.

FIG. 17



Diagrammatic representation of the head of a louse. A, With pricker retracted. B, With pricker extruded. C. Transverse section. P, Piercing organ. CH, Chitinous sheath round base of piercing organ. A, B, C, Dorsal, median, and ventral elements composing piercing organ. ST, Sucking tube. H, Hooklets. M, Muscles of piercing organ. SD, Salivary duct.

Summary of the Position with Regard to the Transmission of Typhus by Lice.

1. The infection of typhus circulates in the blood during and for some time after the febrile period.

2. It is taken up by lice when they feed upon a patient and may be transmitted to monkeys by them.

3. As in the case of fleas and plague, a considerable number of insects, 10 or more, is required to give a reasonable chance of infection to a monkey, an animal which is probably much less sensitive than man.

4. There is reason to believe that the virus proliferates inside the insect, for in order to produce infection by means of blood taken from a patient, the volume required is much larger than could possibly be contained in the lice employed (Wilder).

5. The infectivity of lice endures seven days, and seems to be greater some days after feeding on a typhus patient than immediately (Nicolle and Wilder), but the number of experiments so far performed is not adequate to establish this.

6. There is reason to believe that the infection may be transmissible to a second generation of lice (Wilder).

7. The present limitation of outbreaks of typhus to the most vermin-infested section of the population, its occurrence at a period of the year when the clothing is rarely removed from such persons, and washing of either takes place at considerable intervals, and the practical limitation of the disease to cold climates, all receive ready interpretation on the assumption that lice are essentially the porters of infection.

8. Further support is provided by the non-infectivity of typhus under modern hospital conditions and the success attending prophylaxis directed towards the extermination of insect parasites, and I am unaware of any epidemiological fact inconsistent with the view that lice carry the infection.

The Transmission of African Relapsing Fever by the Tick Ornithodoros Moubata

Relapsing fever is widely distributed about the world, and was at one time very common in this country. In 1868 Obermeier discovered the presence of spirochætæ in great abundance in the blood of patients during the febrile attacks. These were subsequently shown to be the cause of the disease. In 1905 Dutton and Todd (1905) in the Congo and Koch (1905) in German East Africa discovered that the

tick fever of Africa was relapsing fever, and that the spirochæta was conveyed from patient to patient by the tick *Ornithodoros moubata.*

Bionomics of Ornithodoros Moubata.

These ticks are common in the native caravan routes. The adult feeds several times and lives a long time. They are very hardy insects, and can endure many months without food both in the larval and adult stages. In their habits they more resemble the bed bug than the majority of the Ixodes; during the day they hide in the earth of the floors or in crevices in the walls and roofs, and at night emerge to feed upon the occupants. The female lays several broods of some hundreds of eggs in crevices of the ground. Incubation lasts from eight days to two months, according to temperature. The first moult occurs within the egg. The young larval ornithodoros somewhat resembles its parent, has four legs, but undeveloped sexual organs. It feeds upon blood, moults a few times, after which it is a sexually mature insect.

The number of infected ticks along the caravan routes of German East Africa is considerable. Koch (1905, 1906) found 5 to 15 per cent. contained spirochætæ, and in one instance 50 per cent. of the ticks collected from a particular locality contained spirochætæ.

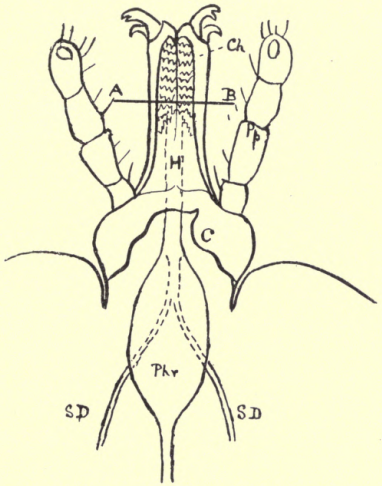
Ticks, once infected, may retain the infection and transmit it to their progeny, for Dutton and Todd (1905) and Koch (1905–1906) found that young ticks raised from the egg were infective. Möllers (1908) further discovered that the second generation from infected ticks were also capable of giving rise to relapsing fever. The same fact was demonstrated by Hindle (1912) for *Spirochæta gallinarum* and *Argas persicus*, the fowl tick. These facts no doubt account for the large proportion which harbour the infection.

The precise mechanism of transmission in relapsing fever is still uncertain. For a few days after feeding on an infected animal Dutton and Todd (1905) and Koch (1905) found the spirochætæ in the alimentary canal of the tick. Subsequently they disappeared from the stomach and gut, but were found by these observers in some of the internal organs, ovaries, Malpighian tubes, and salivary glands.

Leishman (1909), working in London upon a number of ticks sent from Africa, failed to find spirochætæ, although the ticks were capable of infecting monkeys. He noticed, however, that the cells lining the Malpighian tubes contained large numbers of minute chromatin-containing granules, and that similar granules were present in the ovary and eggs of ticks which subsequently gave rise to infective individuals. Ticks in which he failed to find these granules did not give rise to infection.

From these and other observations Leishman was led to the conclusion that the chromatin granules represent a stage in the development of the parasite. These interesting observations have been confirmed by Balfour (1911) in the

FIG. 18.



Section across A B above

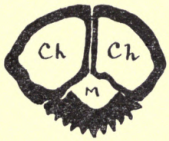


Diagram of mouth parts of tick. Ventral portion of capitellum removed. PP, Pedipalps. CH, Chelicerae. H, Hypostome. C, Capitellum. PHR, Pharyngeal pump. SD, Salivary ducts. M, Tube leading to mouth.

analogous case of *Argas persicus* and fowl spirochætæ. Some experiments by Hindle (1911) also have a bearing upon this point. Hindle failed to find any spirochætæ in infected ticks kept some time at 21° C., but similar ticks warmed up to 35° C. for a few days showed spirochætæ throughout the body and at the same time all the organs were infective.

The Structure and Arrangement of the Mouth Parts and Alimentary Canal of Ornithodoros Moubata.

The general arrangement of the mouth will be seen from the diagram. (Fig. 18.) The boring instrument or rostrum consists of three parts, two cheliceræ (*ch.*) and a ventral hypostome (H.). The cheliceræ are hollow chitinous organs, inside which are muscles which operate the terminal claws ; the hypostome is barbed. In the act of boring the claws are straightened and the three parts of which the rostrum is composed are advanced a little further. The claws are again advanced for a further pull, and the barbed hypostome prevents any slipping back. By a succession of these efforts the rostrum is buried in the skin.

FIG. 19.

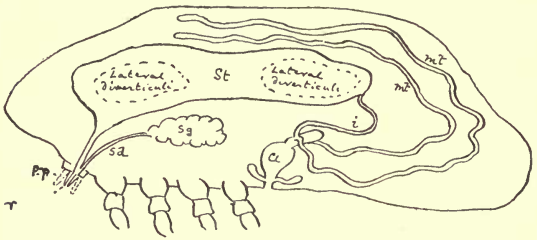


Diagram of alimentary canal and mouth parts of tick (Ornithodoros moubata). PP, Pedipalps. R, Rostrum. SD, Salivary duct. SG, Salivary gland. ST, Stomach. I, Intestine. CL, Cloaca. MT, Malpighian tube.

The three instruments of the rostrum, when apposed, form a canal at the base of which is the mouth. This widens into a pharynx, which is alternately compressed and expanded by a coördinated contraction of the individual muscle fibres attached to it. The blood is driven by the pump through the narrow œsophagus into the crop or stomach (Fig. 19) (*st.*). The stomach is a capacious pouch having extensive lateral diverticula, which themselves branch so that after a full meal the organ distends the insect. The intestine is a very narrow tube connecting the stomach to the cloaca (*c.*). The anus is not terminal, but opens in the mid-line just behind the last pair of legs. The salivary glands (*s.g.*) are of the compound racemose type, each with one duct (*s.d.*) passing forward to the mouth.

Koch was of opinion that the spirochætæ passed from the salivary glands during the act of sucking, but both

Leishman and Hindle consider that the infection is not transmitted by this channel, but that the infective excrement from the Malpighian glands passing out per rectum is washed into the puncture made by the insect by means of the coxal secretion which is deposited during the latter stages of feeding.

The Transmission of the Relapsing Fevers of Europe, America, and India.

Whether the spirochætæ which are responsible for relapsing fever in various parts of the world represent distinct species (Novy and Knapp (1906), Uhlenhuth and Haendel (1907)), or merely varieties, does not seem to me proven in view of the observations of Darling (1909) and Manteufel (1908). Anyhow, they are very similar and all can be transmitted by the tick *Ornithodoros moubata* (Manteufel (1908) and Neumann (1909)). It is, however, clear that this tick was not the transmitting agent in Ireland and England, where relapsing fever was common 50 years ago, nor is it so in Russia, America, or India at the present time.

The epidemiology of the disease in these countries is not yet clear. Spirochætæ are such obligatory parasites that the agency of an insect transmitter seems almost necessary. The only certain way of producing the disease is by inoculating a minute quantity of the blood of a patient during the febrile stage. Spirochætæ have been found in the urine, but no one has succeeded in producing infection by this means. It must also be remembered that they can find their way through the unbroken skin.

The distribution of relapsing fever among the population is consistent with the view that insects are necessary, for, like typhus, this disease in Europe is almost confined to the poorest and dirtiest members of the community. It has been frequently suggested that bugs might disseminate the disease ; Tictin (1897) and Karlinski (1902) found that the stomach contents of the bed bug remained infective for two or three days after feeding on the blood of a patient ; and Kladnitzky (1908) observed appearances strongly suggestive of multiplication of the spirochætæ in the stomach of the bug. With one exception, however, all the numerous attempts to transmit the disease by the bed bug have been unsuccessful. Experiments have also been made with fleas by Sergent and Foley (1908) and others. The results were negative ; a further reason for doubting the importance of either of these insects is that the disease is not more prevalent at the time of year when these insects abound, but rather the contrary, for in Europe, although the disease occurred in epidemic form throughout the year, the greatest prevalence was usually during winter and spring.

The only remaining ectoparasites are lice, *Pediculus capitis* and *Pediculus vestimenti*. The general bionomics of these insects has been dealt with, and it only remains to point out that their prevalence is not confined to the warmer months, but is greatest during the winter (Hamer, 1910), when clothes are least changed and washed.

Mackie (1907), in an investigation of an outbreak of relapsing fever in a mission school in India, brought forward some rather striking epidemiological facts pointing to lice rather than bugs as being concerned with the epidemic. He found spirochætæ in 14 per cent. of the lice taken off the boys. They were present in the alimentary canal, ovary, and Malpighian tubes of these insects. From his observations he came to the conclusion that spirochætæ multiplied greatly in the stomach of the insect, reaching their maximum on the third day. Mackie fed lice from the patients upon monkeys, but he failed to transmit the disease.

In two experiments by Sergent and Foley (1910) relapsing fever followed the infection of the clothing by lice from patients.

The spirochætæ of relapsing fever infect rats, and Manteufel (1908) made some excellent observations on the capacity of the rat louse (Hæmatopinuss) to transmit the disease. He first ascertained by 40 experiments that when free from lice sick and healthy rats could be caged together without the latter contracting the disease, and then repeated the experiments with the addition of lice. Two infected rats were caged together with seven healthy ones. The sick animals were killed by ether at the height of the disease and then put back into the cage in order that the lice upon them might crawl off the cadaver and attach themselves to the living animals. Three of the seven became infected. In another similar experiment with *Spirochæta duttoni* one out of eight rats became infected. Manteufel could not find spirochætæ in the louse outside the alimentary canal, nor in the eggs.

These experiments were confirmed by Neumann (1909) so that it seems highly probable that relapsing fever is spread by lice as well as by the tick *Ornithodoros moubata*. Although the former agent may not be nearly so efficient as the latter, it may make up by its greater numbers and persistency.

The details of transmission by lice are still unknown, but from the habits of these insects to freely discharge the contents of their alimentary canal during feeding, and the readiness with which spirochætæ can penetrate uninjured epithelium, it is not difficult to imagine how this may happen, even supposing the salivary secretion does not contain the infection.

Transmission of Poliomyelitis by Stomoxys Calcitrans.

At the International Congress on Hygiene held in Washington last September, Rosenau announced that he had succeeded in conveying poliomyelitis from an infected monkey to several other monkeys by means of the bites of *Stomoxys calcitrans*, the small biting stable-fly. This observation has recently been confirmed by Anderson and Frost (1912). Three monkeys exposed daily to the bites of 300 stomoxys which had previously fed on two infected monkeys during the whole course of their illness all developed the disease seven to nine days after their first exposure. The observation is of particular interest because hitherto the transmission of poliomyelitis by the subcutaneous inoculation of blood from an infected monkey has been very uncertain even when large quantities of blood have been transferred. It suggests that either the previous experiments have been made at the wrong stage of the disease, or else that the virus multiplies or intensifies in the body of the fly.

The incidence of the disease being summer and autumn is consistent with insect transmission, but the continuance of the epidemic in Sweden after flies had disappeared indicates that there are other means of spread.

Bed Bugs (Cimex lectularius) as Porters of Infection.

The general career of the bed bug is more or less familiar to most people, but it may not be unnecessary to point out that, unlike fleas, there is no larval or pupal stage, but the insect emerges from the egg as a little bug. For the following facts I am indebted to my colleague, Mr. Bacot, who has made observations on this subject.

The young bug sucks blood on the earliest opportunity, grows and moults, and feeds again. After five moults it is a sexually mature and adult insect. Bugs only visit their host for food, and then preferably at night; they strongly resent light, and during the day hide themselves in some cranny of the room or furniture. They are very hardy, and do not require the constant feeding which is so troublesome in breeding lice and fleas. They can survive without food for six months or more. A bug which has imbibed a good meal retires to some secluded spot and slowly digests it. It is some days before it develops a fresh appetite and sallies forth again in search of prey.

The Arrangement of the Alimentary Canal and Mouth Parts of the Bed Bug.

The general scheme of the alimentary canal will be sufficiently clear from the diagram (Fig. 20). There are two pairs of salivary glands (*s.g.* and *s.g.*[1]), and the duct of the larger or dorsal pair (*s.g.*[1]) bifurcates shortly after it emerges from the gland and both tubes run forward to the base of the piercing organ. The exact way in which the three salivary ducts on each side terminate has not yet been determined. The mouth parts also differ from those of the flea in that the sucking tube is made up by the apposition of four elements instead of three. These are two maxillæ (*mx.*) and two mandibles (*mn.*). When not in use these delicate piercing instruments are carried in a groove on the dorsal aspect of the three-jointed labium (*l.*). Whilst feeding this support is folded backwards under the head.

Experiments on the Transmission of Relapsing Fever, Typhus, and Plague by means of Bed Bugs.

The observations of Tictin have already been referred to. Although these show that the spirochætæ of relapsing fever may live from some hours to many days, according to circumstances, in the stomach of the insect, they give no information as to whether the bed bug can in a natural way transmit the disease.

Christy (1902), M. Rabinowitch (1907), and Shellack (1909) tried the experiment on themselves without success. Their attempts were very thorough. Shellack, for instance, fed 168 bugs, which had been previously nourished on a diet of rat blood infected with *Spirochæta recurrentis*, upon himself. The experiment lasted a month, and was so arranged that a variety of intervals elapsed between the ingestion of infected blood and the second meal.

Breinl, Kinghorn and Todd (1906), Rabinowitch (1907), and Sergent and Foley (1910) have also tried to transmit relapsing fever to monkeys by means of bugs. Large numbers of insects were employed by the former observers, sometimes as many as 590 to one monkey. Their experiments were carried on over two or three months. Bugs which had fed upon an infected monkey at all stages of the disease were used, and the interval between feeding upon the infected and healthy animal varied. Nevertheless, no transmission of the disease occurred.

The only case of successful transmission was one experiment by Nuttall (1907), who removed a bug shortly after it had commenced to feed upon an infected mouse and allowed it to complete its meal upon a normal mouse.

Bed bugs were excluded from consideration as transmitters

FIG. 20.

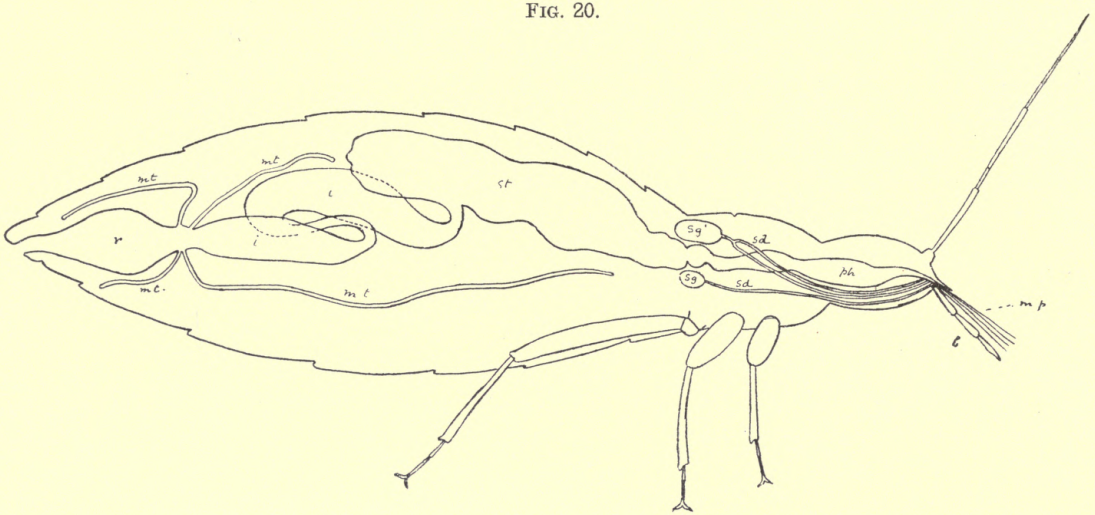


Diagram of alimentary canal and mouth parts of bug (Cimex lectularius), constructed from dissections by Mr. Bacot. MP, Mouth parts (pricker), composed of two maxillæ and two mandibles. L, Labium, in which MP are carried. PH, Pharyngeal pump. SG, Salivary glands. SD, Salivary ducts. ST, Stomach. I, Intestine. R, Rectum. MT, Malpighian tube.

of typhus by Nicolle (1910) and by Wilder (1911), as the distribution of these insects both in time and space does not coincide with that of typhus. Wilder, however, tried experimentally to convey the disease from monkey to monkey by bugs, but without success.

Verjbitski (1904) made a number of experiments on the transmission of plague by the bed bug. He showed that plague bacilli multiply in the stomach of bugs as they do in that of fleas, and that their virulence was unimpaired. He succeeded in conveying plague to guinea-pigs by the bites of bugs, but only up to four days after they had fed on an infected animal.

There is really no evidence to incriminate the bed bug in the case of either typhus or relapsing fever. It is possible to transmit plague experimentally by means of bugs, but there is no epidemiological reason for supposing this takes place to any extent in nature.

There are two differences in the habits of bugs and those of fleas and lice which may possess epidemiological significance. The first concerns the customary intervals between their meals. Bugs show no disposition to feed for a day or two after a full meal, whereas fleas and lice will suck blood several times during the 24 hours. The second is in respect to the time the insects retain a meal and the extent to which it is digested before being excreted. Fleas and lice if constantly fed freely empty their alimentary canals, and the nature of their fæces indicates that the blood has undergone but little digestion.

Both these insects evacuate such undigested, or half digested, blood per rectum during the act of feeding, and the remnants of the previous meal are thus deposited in the immediate vicinity of a fresh puncture. It is not unlikely that, should the alimentary canal of the insect be infected with plague bacilli, spirochætæ, or the organism responsible for typhus fever, these may be inoculated by rubbing or scratching. Bugs have not this habit, and in all the cases I have examined their dejections were fully digested, almost free from protein, and consisted mostly of alkaline hæmatin.

This is, however, probably not the whole explanation, and there is, I believe, much yet to learn as to the mechanisms of insect transmission, and why one blood-sucking parasite is an effective porter and another not, even in the cases of bacterial infection where no stage in the life cycles of the organism takes place within the insect host.

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